N72-10111

NASA CR-111977

SUMMARY FINAL REPORT
BIOWASTE RESISTOJET PROPELLANT SYSTEM
BIOLOGICAL AND FUNCTIONAL ANALYSIS
TASK I and II

September 1971

Prepared Under Contract NAS1-10431

by

THE BIONETICS CORPORATION
18 Research Drive
Hampton, Virginia 23366

for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LANGLEY RESEARCH CENTER
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PREFACE

This summary final report, Biowaste Resistojet Propellant System Biological and Functional Analysis, is submitted by The Bionetics Corporation to the National Aeronautics and Space Administration, Langley Research Center, Hampton, Virginia, as required by Contract Number NAS1-10431. The work was conducted under the technical direction of Mr. Earl VanLandingham of the Space Technology Division of Langley Research Center. This final report is a summary of the work accomplished during the study and reported in detail in the interim monthly progress reports under the contract.

Requests for further information concerning this report or the details contained in interim reports may be directed to

J. R. Wrobel

Resistojet Systems Project Engineer

ACKNOWLEDGEMENTS

Acknowledgement of support in the performance of this study is extended to the following personnel of The Bionetics Corporation.

L. Davies, Propulsion System Analysis

G. Freedman, Environment Control and Life Support

F. Nayor, Propulsion Program Planning

W. Paik, Life Sciences

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UNITS OF MEASUREMENTS

Units, abbreviations, and prefixes used in this report correspond to the International System of Units (SI) as prescribed by the Eleventh General Conference on Weights and Measures and presented in NASA Report SP-7012. The basic units for length, mass, and time are meter, kilogram and second respectively. Throughout the report, the English equivalent (foot, pound, and second) are presented for convenience.

The SI units, abbreviations, and prefixes most frequently used in this report are summarized below:

Basic Units

Length	meter	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Temperature	degree Kelvin	^{o}K

Supplementary Units

Plane angle	radian	rad

Derived Units

Area	square meter	m^2	
Volume	cubic meter	m^3	
Frequency	hertz	Hz	(s^{-1})
Density	kilogram per cubic meter	kg/m^3	
Velocity	meter per second	m/s	
Angular velocity	radian per second	rad/s	
Acceleration	meter per second squared	m/s^2	
Angular acceleration	radian per second squared	rad/s^2	

Force	newton	N	(kg-m/s^2)
Pressure	newton per sq meter	n/m^2	
Kinematic Viscosity	sq meter per second	m^2/s	
Dynamic Viscosity	newton-second per sq meter	N-s/m^2	
Work, energy, quantity of heat	joule	J	(N-m)
Power	watt	W	(J/s)
Electric charge	coulomb	C	(A-s)
Voltage, potential difference: electromotive force	volt	V	(W/A)
Electric field strength	volt per meter	V/m	
Electric resistance	ohm		(V/A)
Electric capacitance	farad	F	(A-s/V)
Magnetic flux	weber	Wb	(V-s)
Inductance	henry	H	(V-s/A)
Magnetic flux density	tesla	T	(Wb/m^2)
Magnetic field strength	ampere per meter	A/m	
Magnetomotive force	ampere	A	

Prefixes

Factor by which unit is multiplied	Prefix	Symbol
10^6	mega	M
10^3	kilo	k
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	

1.0 INTRODUCTION

The use of a resistojet propulsion system for low thrust attitude control functions on long-term manned spaceflights in earth orbit has been identified and studied under several recent NASA contracts. Resistojets have been shown to effectively provide the low acceleration thrusting which is advantageous for applications where less than 10^{-5} 'g' is required for experimental purpose. The propulsive functions of such a resistojet system application could include atmospheric drag make-up and desaturation of rotary momentum storage (Control Moment Gyro) stabilization mechanizations.

An additional advantage of resistojets in manned flight applications is that gases and fluids residual to the crew environment control and life support mechanization can be used as the propellant media. These fluids, generically referred to as "biowastes", are available from a variety of spacecraft sources depending upon the crew support system mechanizations selected. The biowaste material must either be regenerated, vented into space or returned to earth via the logistics support system. On-board regeneration of biowaste generally requires the addition of process equipment and the consumption of electrical power. Venting into space can result in spacecraft external contamination, depending upon the fluid composition. Return-to-earth requires accumulation in the spacecraft, transfer to the logistic vehicle and transport

to earth. The disposal solution for a particular biowaste material depends upon the consideration of the relative complexity of the above alternatives.

The diversion of biowastes through the resistojet propulsion system permits effective mass utilization, i.e. eliminates the separate disposal problem and removes the requirement to supply a separate propellant. Spacecraft contamination by the material vented through the resistojet system can be reduced or eliminated by careful selection of biowaste sources and operation at temperatures above critical limits specific to the biowaste chosen.

The use of biowaste propellant in the resistojet propulsion system may introduce contamination problems internal to the propulsion system. A principal potential problem is the accommodation of the thruster heater elements and supply plumbing to contaminant laden throughputs. This contamination may detrimentally effect life and reliability through mechanical blockage of flow paths, by deposits, or by chemical attack and deterioration of the materials of construction.

Therefore, the specific selection of a biowaste material for resistojet propellant must meet several criteria:

a) the biowaste must constitute a significant mass, power, or cost factor to regenerate, or return to earth, thus being a true surplus to the spacecraft.

b) the resistojet biowaste effluent must not contribute to spacecraft external contamination, i.e. coatings, clouds, particulates, etc.

c) the biowaste must be chemically compatible with reasonably attainable plumbing and thruster fabrication technology.

In addition to these constraints, the biowastes selected must be available in sufficient quantity and duration in the mission to reliably provide the anticipated demands for impulse generating propellant.

Several studies and technology developments have been conducted, or are in progress, which bear on portions of the biowaste selection problems. NASA contracts NAS1-10127 and NAS1-10170 have studied the biowaste resistojet conceptual design and mission interfaces, i.e. EC/LS interactions and modes, impulse demands, mass availability, etc. Other contracts have developed thruster materials and design technology. An area which was not under detail study was the survey of the trace contaminants present in the candidate biowastes and their potential impact upon the resistojet thruster, collection system and operating mode selections.

To accomplish the survey and evaluation of the potential influence of contaminants in the biowaste supplies, The Bionetics Corporation was awarded a 9-month Biowaste Resistojet Propellant System Biological and Functional Analysis Contract (NAS1-10431) by

the National Aeronautics and Space Administration (NASA). The magnitude of the study effort was approximately 3/4 of a man-year.

1.1 Study Guidelines

The evaluation of specific biowaste sources of propellant requires the specification of the functional characteristics of the manned space-station crew support systems, and any other available sources of biowaste material for propellant.

The mission system guidelines for the purpose of this study model were those derived from the contemporary Phase B Space Station/Base biowaste resistojet studies under contracts NAS1-10127 and NAS1-10170. A summary of these guidelines follows:

The mission application of interest was that of a 12-man space station in 371 - 556 km (200 - 300 n. mi) earth orbit. The crew environment control and life support (EC/LS) systems assumed included four basic functions:

> Atmosphere Purification and Control - for removal of CO_2 and trace gases through a molecular sieve and toxin burner.
>
> Atmosphere Supply and Pressurization System - to maintain atmosphere composition and pressure through use of water electrolysis and a Sabatier reactor with nitrogen supplement for the two-gas

requirement.

Water Management & Humidity Control - to recycle urine and hygiene water through a combination of distillation and reverse osmosis processes to essentially close the water system.

Waste Management - for fecal collection and drying and trash processing.

In addition, the general types of station life-science experiments which reject waste materials were generically to be considered as contingent sources of biowaste if demand warranted.

1.2 Study Scope and Objectives

The objective of this analytical study was to evaluate the influence of chemical contaminants* in the potential biowaste sources upon the design and interface requirements of a biowaste resistojet propulsion system for a space station and/or base. The results of the study are to be used in the technology development program of the biowaste resistojet system and for demonstration test planning by the Government. To accomplish this objective, the scope of the study was required to include the following:

A. The review and enumeration of the contaminant traces in the spacecraft sources of biowaste material.

B. The establishment of nominal sources of biowaste based upon the simplicity of access to the material and the relative purity.

C. The review and evaluation of the types of contaminants which influence resistojet thruster performance and life.

* Chemical contaminants for the purpose of this study are defined to include all compounds present in the biowaste other than carbon-dioxide, water, and methane. The latter are the nominal effluent candidates for the biowaste resistojet.

D. The description of propellant collection and distribution systems contaminant control required to make the input biowaste compatible with the thruster tolerance to contaminants.

E. The definition of the interface requirements and the system technology development considerations associated with the selection of specific biowastes sources.

F. The definition of representative biowaste simulation mixtures for ground-based technology development testing.

G. The establishment of functional requirements for the system demonstration phase of Government testing, considering the true composition of biowaste materials that will be available, and the spacecraft propulsive functions to be performed.

To implement this scope of study activity, the contract was organized into seven major task areas. The tasks are interrelated and were chronologically scheduled to match the outputs of the contemporary systems studies previously referenced.

1.3 Task Descriptions

The seven tasks of the study, exclusive of documentation, were topically divided as follows. The nomenclature of the tasks is consistent with that of the contract schedule.

1.3.1 Biowaste contamination sources identification (Task 3.1)

This task included the survey and definition of the specific contaminants present in the biowaste sources available in a space station/base application. These sources include the environment control and life support effluents and certain experiment residues potentially available as biowaste propellant. These results were used to compare with anticipated thruster input tolerances.

1.3.2 EC/LS system flow (Task 3.2)

This task included the interfacing of the results of the prior task with a defined model of the baseline station waste sources for the purpose of focusing the remainder of the study effort upon a specific set of sources. The timing of this task was coordinated with the mission and system studies of the referenced contracts such that the impulse demands and biowaste mass availability from the sources permitted elimination of marginally qualified biowaste sources. The model of sources was defined in a block diagram format.

1.3.3 Resistojet thruster technology (Task 3.3)

This task objective was to review and collate existing information regarding the performance detriment or risk associated with contaminant laden propellant input to a biowaste resistojet

thruster. Attention was directed to the examination of possible metallurgical or chemical phenomena related to contaminated biowastes.

1.3.4 Propellant conditioner comparative analysis (Task 3.4)

This task objective was to define the degree of propellant contaminant control which will be required of the propellant conditioner for the biowaste sources defined in the prior task model in order that thruster life or performance will not be degraded.

1.3.5 Simulation trade studies (Task 3.5)

This task objective was to provide a recommendation of the ground test gas compositions which would simulate the flight biowaste propellant for the purpose of demonstrating system contaminant tolerances.

1.3.6 Program function flow (Task 3.6)

The objective of this task was to systematically describe the flow of required biowaste resistojet technology development events to illustrate the interfaces associated with the planned use of specific biowaste sources, i.e. fecal water, experiment water, urine, etc. The purpose of the plan is to provide program management visibility.

1.3.7 Propellant system development statement of work (Task 3.7)

The objective of this task was to summarize the functional requirements of the biowaste resistojet propellant supply system for the purpose of providing direction to a development program to fulfill the system functional objectives. This objective included the drafting of an example statement-of-work and the performance of review and evaluation of proposed concepts. This task encompasses the summarization of the prior technical studies into an implementation plan for system development.

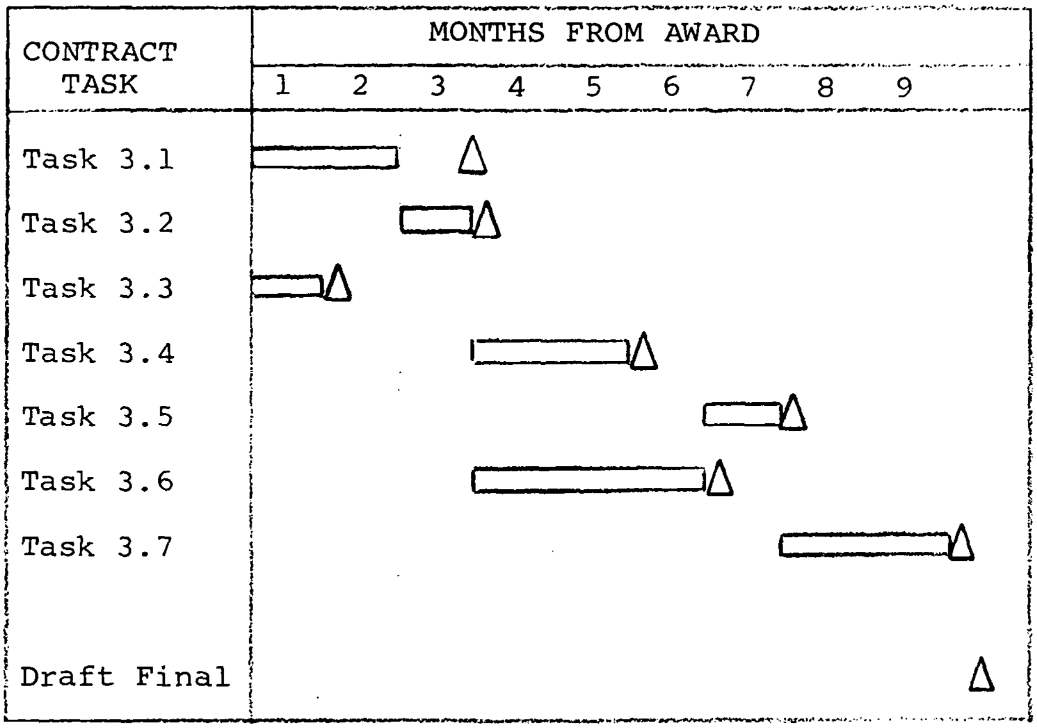
Throughout the study the NASA contract technical representative provided the point of contact for information flow to this study from the other contractor efforts.

1.4 Schedule of Task Performance

The chronological sequence of task performance was scheduled to coincide with milestones of the contemporary Phase B Space-Station/Base Resistojet application studies. The schedule of task performance in this study and the reporting on specific tasks, via the monthly technical progress reports, are described in Figure 1. The task numbering coincides with the definitions of section 1.3.

FIGURE 1

STUDY PERFORMANCE AND MILESTONE SCHEDULE



Legend

Δ- Monthly Technical Progress Report Containing Detail Results

2.0 TECHNICAL SUMMARY

2.1 Biowaste Contamination Sources Identification (Task 3.1)

In the effort to define the types and quantities of contaminants which could be anticipated in the candidate sources of biowaste material, the Environmental Control/Life Support (EC/LS) effluents and certain experiment residues were examined. Through mutual NASA and Contractor selection, the EC/LS Systems as described in the North American Rockwell (NAR) and McDonnel Douglas (MDAC) Space Station Phase B Definition Studies and the EC/LS integrated components of the recent LRC/MDAC 90-Day Space Simulation Test, were used for baseline systems definition.

For this study, the EC/LS System functions were divided into five categories of regenerative activity: the cabin air cycle; potable water loop; wash water loop; urine waste and solid waste cycles. Each of the effluents from these processes were evaluated from the standpoints of a) the constraints the trace contaminants might impose upon the biowaste propellant conditioner and thruster performance; and also b) the time availability, location of source, and quantity. Whenever possible, actual test data (primarily LRC/MDAC 90-Day Space Simulation Test preliminary results) was used in performing the required analyses and judgments. However, as anticipated, it was found that the effluents that exist within these reclamation/treatment processes are complex and variable in

constituency, and in many cases have not been definitively characterized. This was not the case for the Sabatier gases, which constitute the primary resistojet propellant sources. Nor was it the case for the effluent within the potable water loop, for which various standards (United States Public Health Services, Space Science Board, World Health Organization, etc.) have been established. The latter is of importance, since the Space Station/ Base water loop provides one of the most desireable supplies for supplemental resistojet biowaste.

In connection with the investigation of the various potential EC/LS and experiment biowaste propellant sources, a rationale was identified and developed for selection of both supplemental propellant sources (other than the Sabatier input and output) and the point of supply for the supplemental propellant. This rationale stressed that the search for biowaste sources should be restricted to the closest, end-of-process, highest purity or EC/LS rejection point of supply. The selection of a supplemental biowaste source must consider that the effluent is not only available but requires minimal preconditioning in order to be compatible with the RCS. These criteria pointed to the water loops as being the optimum source of supplemental propellant and the question then became one primarily of availability. Simultaneously, other Contractor efforts identified that an excess of water may be available within the Station EC/LS System, if present calculations concerning cabin leakage, food wetness, etc. prove valid.

Therefore, the concentration of effort within this task was placed upon defining the characteristics of the Sabatier input and output effluents and of the potable water.

The approach taken during this task was to examine the three selected EC/LS systems on a component level, summarizing the major characteristics of the various EC/LS mechanizations and tabulating, whenever possible, the quantity and types of contaminants that could be expected to be present within both the primary and candidate supplemental EC/LS - RCS propellant sources. The results, are presented in the First and Third Monthly Letter Progress Reports, and indicate the following:

1) The contaminants identified within the primary EC/LS RCS propellant sources, both upstream and downstream of the Sabatier, do not present a major problem to resistojet performance from a contaminant standpoint.
2) The potable water cycle was selected as the best candidate for supplemental EC/LS - RCS propellant. Within this cycle, the optimum point in which to obtain water was identified and defined as the end of the "clean-up/reclamation" process, but before disinfectant chemicals are added.
3) Data concerning characterization of the brines resultant from the EC/LS reclamation processes is not readily available. However, current resistojet, mission application studies indicate that there does

not appear to be a need for a large amount of supplemental propellant as the Sabatier and CO_2 concentrator/accumulator effluent will provide most of the needed resistojet propellant. Therefore, efforts concerning the characterization of the marginally acceptable effluents need not be exhaustively considered from the standpoint of supplemental resistojet propellant supply.

4) The biowaste effluents originating from Station experiments currently cannot be defined as the experiments themselves have only been detailed to the functional program element level. The inability to characterize, at this time, the quantity and quality of the effluents, their compatibility with present reclamation processes, their availability and other characteristics, preclude their immediate consideration as a supplemental bio-propellant source.

As examples of the contaminant definition performed in this study, Figures 2, 3, and 4 are presented. These charts depict the major subsystem and contaminants present therein for the systems used in technology demonstration tests conducted by M-DAC and NASA Langley Research Center in Summer 1970 (90-Day Life Support Test). Comparable tabulations were made for the other candidates and were presented in the Third Monthly Technical Progress Report.

2.2 EC/LS System Flow (Task 3.2)

In response to the task objective, the schematic functional diagrams of the principal assemblies comprising the biowaste resistojet propellant sources of supply were prepared. The outcome of this work was a baseline definition, for the purpose of this contract, of the most likely biowaste sources for future detail studies of contaminant effects upon propellant conditioner system function and thruster accommodation.

The results of task 3.1 on the biowaste contaminant level, and the reporting by MDAC and NAR on contracts NAS1-10127 and NAS1-10170 respectively, indicated that a) the aqueous sources of biowaste propellant are typically heavily laden with contaminants of diverse and variable composition and b) the impulse demands of the Space Station at most altitudes and years are within the capability of available supplies of atmospheric regeneration gases and water supplement. The reasons for excluding the experiment wastes and sources from the solid waste and trash processing were described in section 2.1. The principal sources identified from the referenced contract work are those of the atmospheric management and reconditioning system and a water source. The water source could be from logistic re-supply, from the potable supply, or from the wash-water loop.

2.2.1 Atmosphere management and reconditioning

The atmosphere reconditioning subsystem provides cabin air thermal control, humidity control, removes trace contaminants, removes carbon-dioxide and electrolyzes water for metabolic and leakage oxygen. The principal functions and elements of this system are depicted in Figure 5. Both M-DAC and NAR preliminary designs incorporate the Sabatier converter for reclamation of oxygen, and a surface-active carbon dioxide concentrator to increase the concentration of CO_2 for use in the Sabatier reactor. The Sabatier outputs are a) methane, b) water and c) traces of hydrogen, oxygen and nitrogen.

The MDAC and NAR approaches to supplying the resistojet RCS system vary due to the characteristics of their respective Space Station Designs. NAR assumes significant (9 kg. (20 lb/day)) leakage of atmosphere and provides an ammonia supply for nitrogen make-up. This provides an excess of hydrogen as well. Also, the NAR design uses cryogenic hydrogen storage for the medium thrust RCS and fuel cells. A certain amount of boil-off is built into this design and the hydrogen vapor is surplus. NAR elects to use this hydrogen surplus as excess reactant in the Sabatier so that carbon dioxide conversion to methane can be more complete. Therefore, NAR recommends very little direct CO_2 dump and uses excess H_2 as a biowaste supplement in the atmospheric sources. MDAC has a lower leakage assumption and uses stored gas for nitrogen make-

<table>
<tr><th>MAJOR SUBSYSTEM</th><th>COMPONENT</th><th>PURPOSE</th><th>COMPONENT PARTS</th><th>OPERATIONAL MODE</th><th>OUTPUT TRACE CONTAMINANTS</th><th>COMMENTS</th></tr>
<tr>
<td>I. WATER MANAGEMENT & HUMIDITY CONTROL</td>
<td>A. VACUUM DISTILLATION/ VAPOR FILTERED (VD/ VF) RECOVERY UNIT.</td>
<td>RECOVERY OF POTABLE WATER FROM URINE AND HUMIDITY CONDENSATE THROUGH USE OF RADIOISOTOPE HEAT SOURCE $^{238}Pu\,O_2$</td>
<td>1. VD/VF BOILER
2. CONDENSER
3. TANK
4. PUMP
5. FILTER
6. Ag^+ GENERATOR
7. O-G USE TANK</td>
<td>1. URINE PRETREATED WITH 4ml/LITER OF SULFURIC ACID-CHROMIC OXIDE SOLUTION IS PUMPED INTO URINE ACCUMULATOR.
2. WATER FROM SILICA GEL BED CONDENSATE AND HUMIDITY CONDENSATE IS ADDED TO FIXED DEMAND OF VD/VF BOILER.
3. EXCESS CONDENSATE WATER IS PROCESSED BY MULTIFILTRATION MODULE.
4. URINE IS VAPORIZED (115°F/0.58 psia) PASSES THROUGH POROUS MATRIX OF TEFLON & STAINLESS STEEL IS SUPERHEATED TO 265°BY FIFTH ISOTOPE SOURCE.
5. VAPOR THROUGH CATALYST BED, IMPURITIES PRODUCED DURING EVAPORATION OXIDIZED TO WATER & CO_2.
6. WATER CONDENSED GOES TO ACCUMULATOR, NONCONDENSIBLE GASES ARE VENTED.
7. AFTER VD/VF, CONDENSATE WATER IS TRANSPORTED TO SILVER ION GENERATOR.
8. (Ag^+) IN OUTPUT WATER = 200 ppb.</td>
<td rowspan="2">POTABLE WATER
<table>
<tr><th>CHARACTERISTIC</th><th>ACTUAL TEST RESULTS</th><th>TEST REQUIREMENTS (Supplemented Space Science Board Standards).</th></tr>
<tr><td>TURBIDITY</td><td>8</td><td>10 ppm SiO_2</td></tr>
<tr><td>COLOR</td><td>0</td><td>15 COBALT UNITS</td></tr>
<tr><td>TASTE</td><td>none-objectionable</td><td>none-objectionable</td></tr>
<tr><td>ODOR</td><td>none-objectionable</td><td>none-objectionable</td></tr>
<tr><td>FOAMING</td><td>none-persistant</td><td>none-persitatnt>15 sec.</td></tr>
<tr><td>pH</td><td>4.2</td><td>no standard</td></tr>
<tr><td>CONDUCTIVITY</td><td>44</td><td>no standard μmho-cm^{-1}</td></tr>
<tr><td>As</td><td>$\leq$ 0.013</td><td>0.5 mg/l</td></tr>
<tr><td>Ba</td><td>0.019</td><td>2 mg/l</td></tr>
<tr><td>Be</td><td>0.0001</td><td>no standard mg/l</td></tr>
<tr><td>B</td><td>0.08</td><td>0.5 mg/l</td></tr>
<tr><td>Cd</td><td>0.002</td><td>450 mg/l</td></tr>
<tr><td>Cl^{--}</td><td>0.0</td><td>no standard mg/l</td></tr>
<tr><td>Cr</td><td>0.001</td><td>3 mg/l</td></tr>
<tr><td>Cu</td><td>0.013</td><td>2 mg/l</td></tr>
<tr><td>F</td><td>- - -</td><td>1 mg/l, pH >7</td></tr>
<tr><td>NH_3</td><td>1.8</td><td>10 mg/l, pH <7</td></tr>
<tr><td>TOC</td><td>28</td><td>no standard</td></tr>
<tr><td>Br</td><td>0.0</td><td>1 mg/l</td></tr>
<tr><td>Cr^{+6}</td><td>0.6</td><td>0.05 mg/l</td></tr>
<tr><td>Pb</td><td>0.006</td><td>0.2 mg/l</td></tr>
<tr><td>Se</td><td>< 0.013</td><td>0.05 mg/l</td></tr>
<tr><td>Ag</td><td>0.011</td><td>0.5 mg/l</td></tr>
<tr><td>SO_4</td><td>- - -</td><td>250 mg/l</td></tr>
<tr><td>TOTAL SOLIDS</td><td>- - -</td><td>1000 mg/l</td></tr>
<tr><td>NO_3 as N</td><td>0.0</td><td>no standard</td></tr>
<tr><td>NO_2 as N</td><td>0.03</td><td>no standard</td></tr>
<tr><td>TOTAL NO_3 and NO_2 as N</td><td>0.03</td><td>10 mg/l</td></tr>
<tr><td>COD</td><td>- - -</td><td>100.00 mg/l</td></tr>
<tr><td>MICROBIOLOGY</td><td>0</td><td>10 total CC</td></tr>
</table>
TEST RESULTS COMPILED FROM POTABLE WATER ANALYSIS OBTAINED DURING MDAC/LRC 90-DAY MANNED SPACE SIMULATOR TEST.</td>
<td>1. CAN PROCESS 24/lbs/DAY
2. REQUIRES FOUR HEAT SOURCES PRODUCING 75 WATTS THERMAL ENERGY TO VAPORIZE URINE MIXTURE AT 115°F AND 0.58 psia.</td>
</tr>
<tr>
<td></td>
<td>B. WICK EVAPORATOR UNIT.</td>
<td>BACK-UP FOR THE VD/VF UNIT FOR RECOVERING POTABLE WATER FROM URINE</td>
<td>1. SIX WICK PACKAGES
2. URINE DISTRIBUTION FEEDERS
3. AIR FLOW CONTROLS</td>
<td>1. WICK CAUSES EVAPORATION OF WATER, SOLIDS STAY IN WICK.
2. CAN BE BY-PASSED PROVIDING UNRESTRICTED AIRFLOW TO HUMIDITY CONTROL UNIT.</td>
<td>WICK CAN HANDLE URINE PRODUCTION OF 4 MEN/ 15 DAYS.</td>
</tr>
<tr>
<td></td>
<td>C. HUMIDITY CONTROL AND MULTIFILTRATION UNITS</td>
<td>PROCESSING OF CABIN AIR FOR HUMIDITY CONTROL AND REMOVES URINE DISTILLATE WHEN WICK EVAPORATOR IS USED AS A BACK-UP TO THE VD/VF UNIT</td>
<td>1. CHARCOAL BED
2. FILTER
3. CONDENSER SEPARATOR
4. MULTIFILTRATION MODULE
a. TWO TANKS
b. MECHANICAL FILTRATION
c. ACTIVATED CHARCOAL FILTER
d. TWO ION EXCHANGE COLUMNS
e. FINELY ACTIVATED CHARCOAL COLUMN
5. FOUR O-G HOLDING TANKS</td>
<td>1. DOWN STREAM OF WICK EVAPORATOR AIR GOES THROUGH CHARCOAL BED TO REMOVE ORGANICS FROM CABIN AND FROM URINE EVAPORATION PROCESS.
2. HYDROPHOBIC/HYDROPHILIC CONDENSER-SEPARATOR CONDENSES AND REMOVES WATER FROM AIR STREAM.
3. MOST WATER DELIVERED TO VD/VF WHEN IT IS OPERATING OR TO MULTIFILTRATION BACKUP SYSTEM.
4. WATER PASSED TO HOLDING TANK (160°F/6 HOURS FOR STERILIZATION).
5. AFTER HEAT TREATMENT WATER IS PASSED THROUGH MULTIFILTRATION MODULE.
6. PASSED TO FOUR FINAL STORAGE TANKS.</td>
<td rowspan="2">
<table>
<tr><th>Turbidity (ppm SiO_2)</th><th>Color (Cobalt Units)</th><th>Odor</th><th>Foaming</th><th>pH</th></tr>
<tr><td>2</td><td>0</td><td>Bland</td><td>None</td><td>3.4</td></tr>
<tr><td>170</td><td>Cloudy</td><td>Slight</td><td>Slight</td><td>3.8</td></tr>
</table>
<table>
<tr><th>SPECIFIC CONDUCTIVITY ( )</th><th>TOC (mg/l)</th><th>TDS (mg/l)</th><th>MILLIPORE FIELD MONITOR 48-HOUR COUNT (No./ml) Hot (160°F)</th><th>Cold (100°F)</th></tr>
<tr><td>310</td><td>151</td><td>191</td><td>2</td><td>6</td></tr>
<tr><td>335</td><td>258</td><td>669</td><td></td><td></td></tr>
</table>
* NO STANDARDS PRESENTLY EXIST FOR WASH WATER. THE ABOVE RESULTS WERE COMPILED DURING THE MDAC/LRC 90-DAY MANNED SPACE SIMULATOR TEST.</td>
<td>1. WATER NOT PROCESSED BY VD/VF IS PROCESSED BY MULTIFILTRATION BACKUP MODULE. (AV. 5lbs/DAY WHEN VD/VF IS OPERATING AND 27lbs/ DAY WHEN VD/VF IS NON-FUNCTIONAL.)
2. MULTIFILTRATION COLUMNS CAN BE STERILIZED BY PERIODIC PASSAGE OF HOT WATER.
3. WATER PROCESSED BY MULTIFILTRATION IS STORED AT 160°F.</td>
</tr>
<tr>
<td></td>
<td>D. WASH WATER RECOVERY UNIT</td>
<td>RECOVERY OF WATER FROM WASH EFFLUENT</td>
<td>1. TWO TANKS (ONE HOLDING HEATED, ONE HEATED USE)
2. FILTERS (MECHANICAL AND ACTIVATED CHARCOAL)
3. ION EXCHANGE RESIN COLUMNS
4. HEAT EXCHANGE</td>
<td>1. WASH WATER RECOVERY LOOP EMPLOYS TWO TANKS: ONE HEATED, HOLDING TANK AND ONE HEATED USE TANK.
2. WATER IS RECOVERED AND PASSED FROM A PROCESS TANK THROUGH A SERIES OF FILTERS WITHIN A FILTRATION MODULE TO A HEATED USE TANK.
3. WATER IS THEN PASSED THROUGH HEAT EXCHANGE BEFORE USE.</td>
<td>BASIC H (SHAKALEE PRODUCTS) USED AS CLEANSING AGENT.</td>
</tr>
<tr>
<td>II. ATMOSPHERE SUPPLY & PRESSURIZATION SUBSYSTEM</td>
<td>A. THERMAL CONTROL UNIT</td>
<td>REMOVE SENSIBLE HEAT LOAD OF THE CREW AND EQUIPMENT AND MAINTAIN TEMPERATURE OF 70° ± 5° F</td>
<td>1. FILTERS
2. INLET AND OUTLET ACOUSTICAL TRAPS
3. TWIN BLOWERS
4. EXTENDED SURFACE HEAT EXCHANGER
5. SUPPLY DIFFUSERS
6. TEMPERATURE CONTROLS
7. COOLANT LOOP</td>
<td>1. AIR IS PASSED THROUGH FILTERS INTO A SOUND TRAP.
2. AIR EXITING FROM THE SOUND TRAP IS DISTRIBUTED WITH DUAL BLOWERS TO A HEAT EXCHANGER.
3. NORMAL AIRFLOW IS 2000 cfm(RELATIVELY HIGH).</td>
<td></td>
<td>COOLANT CIRCULATING LOOP UTILIZES SEPARATE RECIRCULATION PUMP AND PREVENTS CONDENSATION BY HOLDING TEMPERATURE ABOVE DEW POINT TEMPERATURE.</td>
</tr>
<tr>
<td></td>
<td>B. CARBON DIOXIDE CONCENTRATOR
1. SOLID AMINE</td>
<td>MAINTAIN PARTIAL (CO_2) AT 4 mm Hg AND TO PROVIDE RELATIVELY PURE CO_2 FOR PROCESSING IN SABATIER</td>
<td>SOLID AMINE
1. THREE BEDS PACKED WITH SOLID AMINE ION EXCHANGE RESIN
2. TWO FANS (ONE REDUNDANT)
3. CONDENSERS
4. COMPRESSORS TO PUMP CO_2 INTO ACCUMULATOR
5. BOILER AND SUPERHEATER
6. WATER PUMPS, TIMER MANIFOLDS AND SEQUENCE CONTROL VALVES</td>
<td>SOLID AMINE
1. DEHUMIDIFIED AIR FROM HUMIDITY CONTROL OUTLET DRAWN INTO UNIT BY FAN.
2. AIR PASSES THROUGH FILTER, THEN CONDENSER WHICH REMOVES EXCESS MOISTURE.
3. AIR ENTERS ABSORBING AMINE CANISTERS WHERE CO_2 IS REMOVED.
4. AIR PASSES TO SECOND AMINE CANISTER WHERE WATER IS CONDENSED AND PASSED TO WATER STORAGE ACCUMULATOR.
5. DESORBTION PROCEDURES:
-WATER PUMPED FROM ACCUMULATOR TO BOILER SUPERHEATER.
-MAKEUP WATER SUPPLIED FROM POTABLE WATER RECOVERY SUBSYSTEM.
-HEAT FROM COOLANOL 35 HEAT FLUID CIRCUIT.
-STEAM (210° F) PASSED THROUGH AMINE BEDS REPLACING CO_2.
6. WHEN CO_2 DESORBED, BED DISCHARGE VALVE IS OPENED TO WATER TRAP AND COMPRESSOR PACKAGE.
7. CO_2 PASSES FROM CO_2 COMPRESSOR TO THIRD CONDENSER TO CO_2 ACCUMULATOR.</td>
<td></td>
<td>SOLID AMINE
THE SOLID AMINE BEDS FUNCTION TO PROVIDE A 40 MINUTE ABSORBTION AND A 20 MINUTE DESORBTION CYCLE.</td>
</tr>
</table>

FIGURE 2

MAJOR SUBSYSTEM	COMPONENT	PURPOSE	COMPONENT PARTS	OPERATIONAL MODE	OUTPUT TRACE CONTAMINANTS	COMMENTS
ATMOSPHERE PURIFICATION AND CONTROL (CONTINUED)	2. MOLECULAR SEIVE	MAINTAIN PARTIAL (CO_2) AT 4 mm Hg AND TO PROVIDE RELATIVELY PURE CO_2 FOR PROCESSING IN SABATIER	MOLECULAR SEIVE 1. CIRCULATION BLOWER 2. TWO SILICA GEL BEDS IN PARALLEL 3. HEAT EXCHANGER 4. TWO MOLECULAR SIEVE BEDS IN PARALLEL 5. SEQUENCE TIMER 6. MANIFOLD AND SEQUENCE 7. CONDENSER 8. O-G WATER SEPARATOR	MOLECULAR SEIVE 1. CABIN AIR IS PASSED FROM CIRCULATION BLOWER TO SILICA GEL BED WHERE MOISTURE IS REMOVED. 2. FLOW ENTERS HEAT EXCHANGER AND IS COOLED TO 45° - 55°F. 3. CO_2 IS REMOVED IN MOLECULAR SEIVE CANISTER AND RETURNED TO CABIN. 4. ALTERNATE SILICA BED (PREVIOUSLY LOADED WITH MOISTURE) IS DESORBED BY FLOW FROM THE MOLECULAR SEIVE BED BEING HEATED TO 300°F TO DRIVE OFF CO_2. 5. GAS PUMPED INTO CABIN TO PURGE RESIDUAL AIR THEN INTO ACCUMULATOR. 6. AFTER DESORPTION AND DURING ADSORPTION ALL CANISTERS ARE SEALED WITH HEAT TRANSFER FLUID.	DIRECT ATMOSPHERIC SAMPLE FROM CO_2 COLLECTOR CONSTITUENT — ppm Freon 11 — 1.74 Freon 113 — 10.1 1-Butene — 0.11 Butene — 0.037 Ethylbenzene — 0.014 Toluene — 0.0072 C_{10} Aromatics — 0.015 Acetone — 7.3 Methyl alcohol — 0.0022 Ethyl alcohol — 0.13 Isopropyl alcohol — 0.1 Isobutyl alcohol — 0.005 Methylchloride — 0.00001 CONSTITUENT — ppm Vinylchloride — 0.019 Methylenechloride — 0.12 Ethylenedichloride — 0.0024 Methylchloroform — 0.0014 Trichloroethylene — 0.00044 Tetrachloro-ethylene — 0.00013 Acetaldehyde — 0.83 Dimethylsulfide — 0.38 * TEST DATA RESULTANT FROM SAMPLING OF GAS FROM ACCUMULATOR TANK DURING MDAC/LRC 90-DAY MANNED SPACE SIMULATOR TEST. HIGH FREON CONCENTRATION WAS DUE TO PRETEST ACCIDENT AND RESULTANT CLEANING.	MOLECULAR SEIVE 90 MIN. FOR THE COMPLETE ABSORBTION, DESORBTION, AND COOLING CYCLE. A LiOH REMOVAL UNIT PROVIDES A REDUNDANT BACK UP CAPABILITY.
	C. TRACE CONTAMINANT REMOVAL/TOXIN BURNER	EFFECT REMOVAL OF CO, H_2 & CH_4 WHICH MAY RESULT FROM LEAKAGE OF THE ELECTROLYCIC UNIT OR SABATIER REACTOR	1. BLOWERS 2. REGENERATIVE HEAT EXCHANGER 3. COOLING JACKET OF SABATIER 4. THERMOSTATICALLY CONTROLLED ELECTRIC HEATER 5. HOPCALITE BED	1. AIR (0.5c/m) DRAWN FROM THERMAL CONTROL DUCT DOWNSTREAM OF BLOWERS. 2. AIR PREHEATER IN REGENERATIVE HEAT EXCHANGER. 3. AIR THEN PASSES THRU COOLING JACKET OF SABATIER WHICH IS HOT ENOUGH TO ALMOST ADEQUATELY HEAT THE TOXIC BURNER AIR STREAM. 4. ADDITIONAL HEAT SUPPLIED BY THERMOSTATICALLY CONTROLLED ELECTRIC HEATER. 5. AIR GOES INTO HOPCALITE CATALYST AT 700°F WHERE CO_2, H_2, CH_4 AND OTHER ORGANIC COMPOUNDS OF LOW MOLECULAR WEIGHT ARE REMOVED. 6. EXIT AIR PASSES THROUGH REGENERATIVE HEAT EXCHANGER. 7. AIR FINALLY RETURNED TO CABIN.		SOME SOLUBLE ORGANIC CONTAMINANTS ARE SCRUBBED FROM ATMOSPHERE IN THE HUMIDITY CONTROL UNIT.
III. ATMOSPHERE SUPPLY & PRESSURIZED SUBSYSTEM	A. SABATIER REACTOR	COMBINE H_2 WITH CO_2 TO FORM METHANE AND WATER VAPOR	1. MIXTURE RATIO CONTROL 2. TEMPERATURE CONTROL 3. REACTOR BED (NICKEL ON KIESELGUHA CATALYST) 4. CONDENSER 5. POROUS PLATE O-G WATER SEPARATOR 6. OUTLET METERING ORIFICE	1. GASSES FED INTO THE SABATIER INCLUDE: H_2 FROM ELECTROLYSIS AND CO_2 FROM CONCENTRATOR. 2. A PAIR OF METERING ORIFICES AND PRESSURE REGULATOR CONTROL GAS FLOW. 3. THE BURN IS LEAN IN H_2 FOR BETTER H_2 EFFICIENCY. 4. THE BED OPERATES AT A STABLE TEMPERATURE OF 700°F AND THE UNIT AT A REACTOR PRESSURE OF GASSES (SLIGHTLY BELOW AMBIENT ATMOSPHERE OF 10 psia H_2 & CO_2). 5. IF EXCESSIVE TEMPERATURE OCCURS, SOLENOID SHUTS H_2 SUPPLY DOWN AND BED IS COOLED BY CO_2.		HEAT PRODUCED BY THE REACTION OF H_2 & CO_2 (140 WATTS PER FOUR MAN SYSTEM IS USED TO PREHEAT TOXIN BURNER AIR.
	B. WATER ELECROLYSIS 1. ALLIS CHALMERS ALKALINE UNIT	CONVERT WATER TO O_2 + H_2: O_2 GOES TO ATMOSPHERE SUPPLY CONTROL, H_2 TO SABATIER	ALLIS CHALMERS ALKALINE UNIT 1. INPUT FEED PUMP 2. WATER ACCUMULATOR 3. TWO PHASE GAS SEPARATOR 4. THREE ELECTROLYSIS MODULES 5. PUMP TO CIRCULATE ELECTROLYTE 6. CONDENSER TO REMOVE H_2O VAPOR FROM PRODUCT GASES 7. BACK PRESSURE REGULATORS TO EQUALIZE $H_2 \cdot O_2 \cdot H_2O$ PRESSURE ACROSS POROUS MATRICES 8. CURRENT CONTROLLER MODULATES CELL CURRENT AS A FUNCTION OF ACCUMULATOR PRESSURE	ALLIS CHALMERS UNIT 1. WATER FROM ACCUMULATOR IS FED TO A TWO-PHASE GAS SEPARATOR. 2. WATER IS THEN PASSED TO THREE ELECTROLYSIS MODULES. A PUMP CIRCULATES THE ELECTROLYTE AND REMOVES ENTRAPPED GASSES. 3. A CONDENSER REMOVES WATER VAPOR FROM THE PRODUCT GASSES. 4. BACK PRESSURE REGULATORS EQUALIZE H_2,O_2 AND WATER PRESSURES ACROSS THE ASBESTOS MATRICES. 5. CURRENT CONTROLLER MODULATES CELL CURRENT AS A FUNCTION OF ACCUMULATOR PRESSURE. 6. COOLING IS PROVIDED BY EVAPORATING WATER FROM THE ELECTROLYTE INTO THE PRODUCT GASSES. CELL IS OPERATED AT 190°F.	NO PROBLEM WITH TRACE CONTAMINANTS ANTICIPATED.	1. UNIT IS RATED AT 10 lb./DAY. 2. O_2 IS SUPPLIED UNDER 50 psia. PRESSURE TO 3.5 CU.FT. ACCUMULATOR. 3. OXYGEN PRODUCTION CAN BE REGULATED BY CONTROLLING ELECTROLYSIS.
	2. LOCKHEED UNIT		LOCKHEED CIRCULATING ELECTROLYTE 1. PUMPS 2. CURRENT CONTROLLER 3. TEMPERATE CONTROLLER 4. ELECTROLYSIS MODULES 5. SURGE TANKS 6. HEAT EXCHANGER 7. ELECTROLYTE 8. GAS SEPARATOR 9. PRESSURE CONTROLLERS	LOCKHEED CIRCULATING ELECTROLYTE 1. PRESSURE REGULATOR ON FEED WATER LINE ADMITS WATER AS WATER IS CONSUMED BY ELECTROLYSIS PROCESS. 2. INLET WATER IS MIXED WITH CIRCULATING ELECTROLYTE THEN IS FED TO CELL MODULES, WHERE IT FLOWS BETWEEN ABSORBENT MATRICES. 3. WATER IS CONVERTED TO HYDROGEN AND OXYGEN GAS UPON CONTACT WITH ELECTRODES. 4. ELECTROLYTE EMERGING FROM CELL MODULES ARE COOLED IN HEAT EXCHANGER BEFORE RECYCLE. 5. GAS SEPARATOR VENTS GAS IN THE FEED WATER.		
	C. ATMOSPHERE SUPPLY CONTROL 1. FLIGHT WEIGHT TWO-GAS CONTROL 2. BREADBOARD TWO-GAS CONTROL (BACK-UP UNIT)	MAINTAIN THE DESIRED ATMOSPHERIC COMPOSITION THROUGH THE ADDITION OF FIXED QUANTITY PULSES OF O_2 + N_2	TWO GAS CONTROL SYSTEM 1. PERKIN/ELMER FOUR-GAS MASS SPECTROMETER 2. BECKMAN OXYGEN ANALYZER 3. STATHAM STRAIN GAGE ABSOLUTE PRESSURE TRANSDUCER 4. POTENTIOMETER 5. INTEGRATING AMPLIFIER 6. RELAYS 7. TIMING CIRCUITS 8. OXYGEN PULSE COUNTER 9. NITROGEN PULSE COUNTER 10. SOLENDID VALUES 11. POWER SUPPLIES	1. EITHER TWO GAS CONTROL SYSTEMS ACCEPTS SIGNAL FROM EITHER TWO SENSORS. 2. SENSOR SIGNAL COMPARED AT SUMMING JUNCTION WITH REFERENCE SIGNAL FROM SET POINT POTENTIOMETER AND ERROR FED TO THE INPUT OF AN INTEGRATING AMPLIFIER. 3. WHEN NEGATIVE ERROR SIGNAL REACHES A PREDETERMINED LEVEL, SENSITIVE RELAY IS ACTUATED AND TIMING CIRCUIT ENERGIZED PROVIDING A SIGNAL THAT CONTROLS SOLENOID THAT ADMITS GAS THROUGH METERING ORIFICE. 4. AMPLIFIER OUTPUT CONNECTED TO SUMMING JUNCTION THROUGH DROPPING RESISTOR RETURNING OUTPUT TO ZERO. 5. AT END OF TIMER PERIOD (NOMINALLY 10 SEC.), SOLENOID VALVE CLOSES AND AMPLIFIER BEGINS TO INTEGRATE AGAIN.		1. DESIGN USE RATE OF O_2 OR N_2 IS PULSE RATE OF 10 PER HOUR. 2. O_2 & N_2 SUPPLIED AT 50 - 100 psia. 3. GAS FLOW THROUGH METERING DEVICE IS SONIC YIELDING CONSTANT FLOW. THUS THE QUANTITY OF GAS PER PULSE CAN BE DETERMINED AND NUMBER OF PULSES COUNTED. 4. MASS SPECTROMETER SENSES O_2,N_2,CO_2 + H_2O IN ATMOSPHERE 5. O_2 & N_2 SIGNAL CAN GO TO EITHER GAS CONTROL UNIT. 6. CO_2 + H_2O SIGNALS DISPLAYED ON METER RELAYS WHICH PROVIDE ALARM SIGNALS FOR OUT OF TOLERANCE VALUES.
IV. WASTE MANAGEMENT SUBSYSTEM	A. FECAL COLLECTOR GENERAL ELECTRIC "SLINGER"	COLLECT & PROCESS FECES COMBINING ZERO G COLLECTION AND VACUUM DEHYDRATION OF FECES & WASTE TISSUE	1. SLIDING SEAT 2. AIR ENTERTAINMENT BLOWERS 3. SHREADERS 4. VACUUM DRYING SYSTEM 5. MICROBIAL FILTER FOR AIR 6. ACTIVATED CHARCOAL FILTER - AIR 7. BAG CONTAINER 8. SLINGER IMPELLER 9. SOLENOID VALVES	1. A SLIDING SEAT IS OPENED AND THE AIR ENTRAINMENT BLOWERS ARE TURNED ON. 2. THE STOOL IS CARRIED INTO A ROTATING SLINGER WHERE IT IS SHREDDED AND SPREAD UNIFORMLY AGAINST THE CONTAINED WALL. 3. AIR IS PASSED THROUGH A MICROBIAL FILTER AND CHARCOAL FILTER FOR ODOR REMOVAL THEN BACK TO THE CABIN. 4. A VACUUM LEVEL OF 1-2 TORR IS SUFFICIENT TO DEHYDRATE THE FECES.	BIOWASTE EFFLUENT WAS NOT CHARACTERIZED. PROGRESS REPORT NAS1-10431 (OCTOBER 16 - NOVEMBER 15) PRESENTS DETAILS FROM COMPONENT TESTING.	

FIGURE 3

MAJOR SUBSYSTEM	COMPONENT	PURPOSE	COMPONENT PARTS	OPERATIONAL MODE	OUTPUT TRACE CONTAMINANTS	COMMENTS
WASTE MANAGEMENT SUBSYSTEM (CONTINUED)	B. URINE COLLECTOR	COLLECT AND TRANSFER OF URINE	1. COLLECTOR 2. CENTRIFUGAL SEPERATOR 3. PRETREATMENT SOLUTION SYSTEM	1. THE URINE COLLECTOR WORKS ON AN AIR ENTRAINMENT PRINCIPLE SIMILAR TO THE FECAL COLLECTOR. 2. UPON COLLECTION OF THE URINE, A METERED AMOUNT OF PRETREATMENT SOLUTION IS ADDED AND THE RESULTING FLUID IS TRANSFERRED TO THE WATER RECOVERY SUBSYSTEM. 3. WATER FROM THE WAS WATER SUBSYSTEM IS USED AS FLUSH WATER.		
	C. WASTE HANDLING 1. DRY 2. WET	COLLECT, STORE OR DISPOSE OF WASTE AND GARBAGE.	1. FIREPROOF BOXES 2. VACUUM CLEANER 3. BACTERICIDE (8-HYDROXYQUINOLINE SULFATE)	1. DRY WASTE (PAPER ETC.) IS BALED AND STORED IN FIREPROOF BOXES OF ABOUT 1ft^3 CAPACITY. 2. WET WASTE (WITH MICROBIAL PROBLEMS) IS PLACED IN CANS, SPRAYED WITH 8-HYDROXYQUINOLINE SULFATE, AND THEN SEALED IN CANS. 3. VACUUM CLEANER FOR LITTER.	THIS TEST DID NOT INCORPORATE A WASTE HANDLING SUBSYSTEM WHICH WOULD ALLOW FOR RETRIEVAL OR REUSE OF ANY WASTE PRODUCTS.	
V. FOOD MANAGEMENT SUBSYSTEM.	A. LITTON MICROWAVE OVEN B. REFRIGERATOR	STORAGE AND PREPARATION OF FOOD		1. FOOD IS FREEZE DEHYDRATED, WRAPPED IN MYLAR FOIL EVACUATED PACKAGES. 2. REHYDRATION IS ACCOMPLISHED WITH HOT AND COLD WATER.	THIS TEST DID NOT INCORPORATE A FOOD MANAGEMENT SUBSYSTEM WHICH WOULD ALLOW FOR RETRIEVAL OR REUSE OF ANY WASTE PRODUCTS.	

NOTES:

1. NO RESUPPLY, ALL FOOD, MAKE-UP WATER, SPARE PARTS AND TOOLS ON BOARD.
2. TEST ATMOSPHERE OF N_2 & O_2 (10psia - 517 TORR) OXYGEN PARTIAL PRESSURE (3 psia - 160 TORR).
3. DESIGN REQUIREMENTS FOR LIFE SUPPORT SYSTEM:
   TOTAL PRESSURE: 10 psia (517 TORR) OXYGEN: 3.1 psia (160 TORR) TEMP: 700°F (294K) RH: 40-70%
   CO_2: 0.0735 psia (3.8 TORR) CREW: FOUR MEN NOISE: 50-60 NCA
4. DATA STORED BY A 200 CHANNEL ANALOG-DIGITAL CONVERTER SYSTEM OR MAGNETIC TAPE FOR PROCESSING ON A SDS 930 COMPUTER. FURNISHES TEMP, PRESSURES, FLOW RATES, POWER CONSUMPTIONS. USED TO DETERMINE POWER & THERMAL BALANCES.
5. SPACE STATION SIMULATOR CHARACTERISTICS:
   12ft DIA x 40 ft LONG DOUBLE WALLED CHAMBER = 4100ft^3, SPACE BETWEEN WALLS & VACUATED TO 4-10" H_2O BELOW CABIN, 4" THERMAL INSULATION.
6. SUPPORTING FACILITY UTILITIES AND SUPPLIES:
   ELECTRIC POWER: 115,208v, 28 VDC, THERMAL CONTROL FLUID: HOT & COLD COOLANOL VACUUM PUMPS.
   GAS: N_2-ATMOSPHERE, O_2-INITIAL PRESSURIZATION AND BACKUP, CO_2-SIMULATING METABOLIC LOADS, O_2 - H_2 - BACKUP FOR ELECTROLYSIS UNIT, H_2O - FIRE EMERGENCY
7. COMMUNICATIONS - THREE CHANNEL INTERCOM, SPEAKERS, HEADSETS, 7 TV CAMERAS, TIME LAPSE VIDEO RECORDER
8. SYSTEM CONFIGURATION CONSIDERATIONS:

FIGURE 4

up. MDAC does not provide cryogenic hydrogen for either RCS thrusting or fuel cells. Therefore, they have no surplus of hydrogen available. Instead MDAC uses the hydrogen from water electrolysis to react in the Sabatier. The MDAC approach is to only react the amount of CO_2 in the Sabatier which is consistent with the hydrogen supply from electrolysis and dump excess CO_2 unreacted. The amount of oxygen lost in the unreacted CO_2 is balanced by the hydrogen converted to methane such that the proportions are those of water.

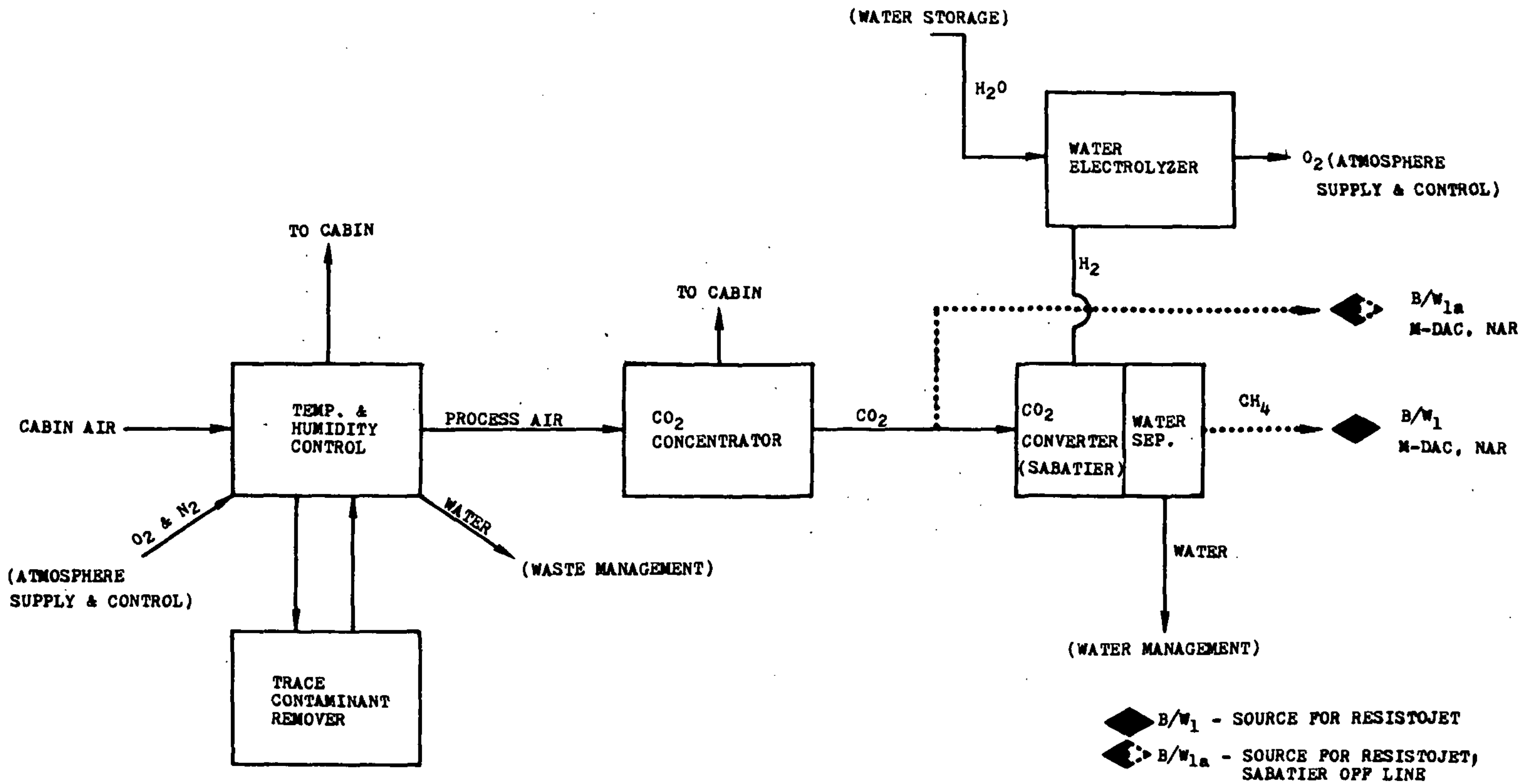
Therefore, using an NAR approach, the propellant source includes H_2, CH_4 and traces of atmospheric N_2 and O_2 with saturated water vapor present. The MDAC source includes CO_2, CH_4 and water vapor and traces of N_2 and H_2. The water product of the Sabatier reactor is chemically pure and should not be dumped into the general water circuit if it can be made available as a biowaste propellant supplement.

2.2.2 Water management

The Water and Waste Management Subsystems control and conserve the water resources of the space station. See Figure 6. Urine and wash water concentrate is processed in the urine water recovery system. Water is sterilized and stored for consumption by the crew in drinking, food reconstitution, or as flush for the urine collector. Water is also supplied from this system to the electrolysis cells. Wash-water taken from storage is used for crew

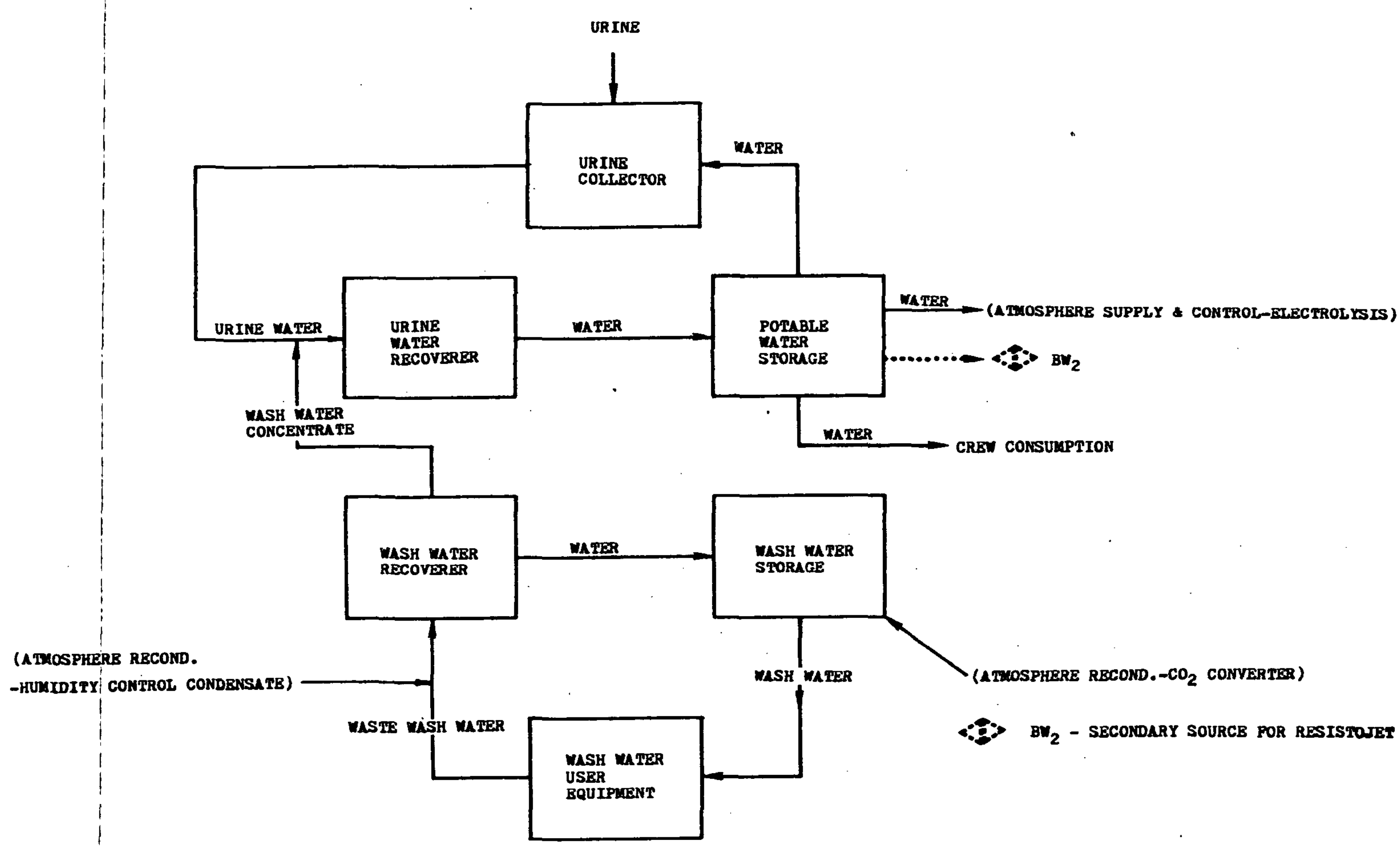
hygiene, the dishwasher and the clothes washer. After use, it is processed in wash-water recovery and sent back to wash-water storage. Periodically, the concentrate from wash-water recovery is directed to the urine water recoverer for processing similar to urine. Both would use reverse osmosis to purify wash-water. NAR would use vapor compression to recover water from urine and wash-water concentrate and McDonnel Douglas would employ wick evaporation. Insofar as potential propellant sources are concerned, both North American and McDonnel Douglas suggest potable water. The amount of water available is dependent upon such factors as EVA water use, fecal water loss, urine water recovery efficiency, water in the food supply, and Sabatier condenser characteristics. Futher detail was presented in the Third Monthly Technical Progress Report.

The use of water as a supplemental propellant is probably the best choice for the Space Station. From the resistojet contamination aspect, the Sabatier water condensate is the best prospect if storage is permitted during low usage periods. This "pure" water is also in demand for water electrolysis and so there is competition for its use. In any case, the pure water should not be degraded by dumping it into the general supply.



ATMOSPHERE RECONDITIONING

Figure 5



WATER AND WASTE MANAGEMENT

FIGURE 6

2.3 Resistojet Thruster Technology (Task 3.3)

The literature pertinent to biowaste resistojet thrusters was reviewed to determine the design areas which are susceptible to performance or life degradations by propellant laden contaminants. At the current state of technology, the primary concern has been in providing long life at high temperature for the heater element when exposed to methane and carbon-dioxide gas mixtures with or without supplement with water vapor. Liquid water is not a satisfactory propellant in current designs because of flow and cooling transients in two-phase (gas-liquid) flow. Rhenium metal elements have proven to be satisfactory for the ammonia and hydrogen resistojets, but are not suitable for use in oxidizing environments. Platinum based alloys with Rhodium have been shown to deplete in Rhodium when used in the carbon-dioxide propellant flow due to formation of volatile carbonyls at elevated temperatures. For these alloys, and perhaps for all designs with long residence time, the dissociation and deposition of carbon from methane is a demonstrated problem. These areas are under separate investigation in other contracts. In particular, Thoria dispersed in Platinum and ceramic Zirconia are under test and evaluation for oxidation and carbonyl resistance.

The use of water as a biowaste resistojet propellant presents new problem areas. The liquid phase aspect can be resolved by use of a separate or integral water vaporizer or flow control to pro-

vide vapor phase propellant to the final heater section. The most significant potential contaminant problem with water as a biowaste is that any but pure, distilled water will contain involatile solids and convey these contaminant compounds to the thrusters or other points of vaporization. Consideration of use, and testing, with typical EC/LS biowaste sources must include the evaluation of the type and quantity of contaminants carried across the interface and the possible influence of these on thruster life and performance. In this regard, the aqueous sources of the EC/LS were reviewed for possible thruster impact.

Numerous salts occur in untreated liquid biowastes and in the aqueous solutions resulting from biowaste processing. Many of these salts have a high degree of solubility in water at the Space Station/Base ambient operating temperature. The equilibrium solubility in water of typical salts was reviewed to bound the potential problem of contaminants in biowaste propellant liquids. Table 1 summarizes the solubility data of interest for typical biowaste supplies. A value of 100 in the table corresponds to equal mass solutions, salt to water.

TABLE 1

SOLUBILITY IN WATER (gm/100gm) OF VARIOUS SALTS AT 18° C(64°F)

	K	Na	Ca	Mg
SO_4	11.1	16.8	0.2	35.4
CrO_4	63.1	61.2	0.4	73.0
OH	142.9	116.4	0.2	0.2
CO_3	108.0	19.4	0.0	0.1
NO_3	30.3	84.0	121.8	74.3
Cl	33.0	35.9	73.2	55.8

The table illustrates that potassium salts are highly soluble, followed by sodium, magnesium, and calcium. Concentrations approaching these in the Space Station/Base EC/LS system would only be found in the reverse osmosis urine or wash-water concentrated brines, and would represent a significant challange to any propellant conditioning system for the biowaste resistojet. The currently achievable reverse osmosis concentration efficiency results in solutions considerably below (about 25% of saturation) these maxima. If the concentrated brines are drawn from a warm processor and distributed to a cooler biowaste liquid propellant storage tank, there may be precipitation of salt in the plumbing system and subsequent blockage. This could also occur if liquid biowastes are distributed to a thruster which has temporarily cooled below ambient due to shadowing or power interruption. At the other end of the salt concentration spectrum, the spacecraft

potable water quality standards were reviewed. Of the three published standards, i.e., World Health Organization, U. S. Public Health Service and Space Science Board, the last was selected as being representative, after discussions with NASA-LRC technical staff members. This standard is summarized in Table 2. The chloride and sulphate content of even the potable water supply represents a potentially significant cumulative problem. For a single 0.22N (50m lb) thruster, the mass flow rate of biowaste propellant is approximately 0.1 gm/sec. If the biowaste resistojet thruster were exposed to the potable water maximum contamination level, then 10^{-4} gm/sec solids throughput is prospect. In 100 hours of operation this constitutes almost 0.4 kg of solids per thruster when operated continuously with marginally potable water. The presence of sulphur and chlorine in the water supply could represent a source of chemical corrosion to heated biowaste thruster parts. In the solicitation for resistojet operating and performance data, made by MDAC under contract NAS1-10127, the more stringent water quality controls of the U. S. Public Health Service were imposed as a water standard for resistojet service. The U.S.P.H.S. total solids limit is 500 ppm, and the chloride limit is 250 mg/l. If the resistojet thrusters are marginally operable in the U.S.P.H.S. water quality, then use with the Space Science Board rated water will constitute a development problem. At this time there does not appear to be data available on resistojet thruster life when exposed to this

water standard.

TABLE 2

SPACE SCIENCE BOARD POTABLE WATER STANDARDS

Compound or Property	Max. Acceptable Concentration
Chloride (mg/l)	450.0
Nitrate	10.0
Sulphate	250.0
Max Solids (ppm)	1000.0

Operation of the biowaste resistojet on urine from the storage tank in the spacecraft increases the potential operating problems because of the urine constituents and also due to the presence of the sulphuric acid and chromic oxide disinfectants added to the storage tank to suppress bacterial growth. The 4ml/liter additive represents approximately 100 ppm solids of sulphate and chromium in the urine solution, which is small compared with urine solids, but the sulphur may represent a new metallurgical corrosion problem. AVCO reports that in 250 hour tests using urine biowaste propellant with Rhenium wire elements, there was no blockage of the nozzle by the solids that form in the vaporization process. The temperature of the heater element was not reported, nor were the results of any metallographic analyses of the wires. Data such as this must be gathered if biowaste resistojet operation with low quality biowaste is to be assumed

for Space Station/Base. The ongoing biowaste resistojet thruster development program under contract at the Marquardt Corporation should provide the additional needed data provided the test fluids are appropriately selected to include the current water standards.

2.4 Propellant conditioner trade studies (Task 3.4)

Under this task, numerous analyses were conducted to assess the significance of the effects of contamination in the biowaste upon system performance. Several conclusions drawn from the analyses provide recommendations for the system functional requirements. It was determined that gaseous contaminants in expected quantities would not grossly influence propellant (gaseous) quantity gaging accuracy except in the case of excess throughput of hydrogen in the Sabatier products. Therefore, for controlled Sabatier operation, simple P,V,T, gaging of gases is adequate. Condensed water carry-over in the Sabatier effluent is shown to provide untapped reserves in the gas storage tanks with a time constant of the order of one month to "dry-out" the tanks in normal operation following a significant water carry-over occurrence. Also, combustion hazards were assessed, resulting in the support for separate gas storage tanks for the Sabatier and CO_2 supplies to minimize hazards. Dissolved salts in the aqueous sources of biowastes were reviewed and evaluated in connection with the contaminant trapping capacity of the water vaporizer(s) of the biowaste propellant system.

The following paragraphs summarize the special topics of propellant conditioner analysis and trade-studies performed. These studies were reported in greater detail in the fifth and sixth monthly progress reports.

2.4.1 Variation in mass storage capacity due to gaseous contaminants

The effluent of the EC/LS system, namely the CO_2 molecular sieve and the Sabatier reactor output will be stored within the biowaste resistojet propellant supply system for intermittent use. The instantaneous estimation of quantity (mass) available will be one function of the propellant control logic system. The presence of non-standard (contaminated) gas mixtures in the supply would influence these quantity estimates if only temperature and pressure are monitored, since the mass will also depend upon mixture molecular weight. An examination of the influence of contaminant gases upon the estimate of mass in the tanks was performed to assess the accuracy of prediction under varying input mixture conditions.

The molecular sieve (CO_2 concentrator) desorbant will be primarily CO_2 with traces of air, i.e. O_2 and N_2. Variation in the efficiency of the desorbtion process will cause the fraction of the constituents to vary. The proportion of O_2 to N_2 will remain constant at the value appropriate for air. The Sabatier reactor will be subject to conversion efficiency changes as the

catalyst ages and the temperature and flow rates change. In these cases, the proportions of CO_2 and CH_4 will change, and the prospect of some hydrogen carry-over is present. The water condensed in the output of the Sabatier could also change due to condenser effectiveness changes with flow rate and temperature, permitting more or less water vapor carry-over. To assess the significance of these effects upon system mass prediction accuracy an analysis was conducted to estimate sensitivity to small changes.

It is apparent that the mass content will only be sensitive to variation in the species with large molecular weight differences from nominal. The CO_2 sieve products are CO_2, N_2 and O_2 with molecular weight of 44, 28, and 32 respectively. Variations in CO_2 desorbtion were studied from the nominal 0.984 mole fraction to 0.936 for CO_2 in the désorbant. The results indicate that a 5% change in CO_2 desorbtion efficiency will change the mass storage estimate by 1.7%. It is doubtful that mass measurement by T and P measurements would be influenced by this small variation. This low sensitivity arises because the possible products are all at nearly the same molecular weight. The Sabatier output products are more variable in molecular weight, i.e. from 16 to 44, and down to 2 if hydrogen carry-over is considered. The nominal mixture molecular weight is 17.71, therefore, variations in water vapor content and methane content will be small

influences in mass estimation accuracy. The presence of liquid water is treated separately. The results indicate a mass estimate percentage error approximately equal to the hydrogen mole percentage if no hydrogen is prospect in the nominal stream.

2.4.2 Effect of liquid water on mass estimation

If, in the operation of the Sabatier output condenser, liquid water is permitted to enter the propellant storage tank, then some mass estimation error can be expected. This situation was analyzed to determine the magnitude of the error experienced.

Water in the storage tank displaces some of the volume which could be occupied by gas. Barring blow-through of liquid water, the water can only escape by evaporation into the output gas. At 27^{o}C and 20 atm. storage pressure, the output gas can carry off approximately 0.00785 kg. dry gas. This evaporation requires approximately 40 kcal. input per kg. of dry gas. This heat would be supplied through conduction from the tank walls and attachments and should not present a problem at the low flow rates of output experienced. The liquid water, if any, represents a conservative error in the storage quantity estimate since its density as a liquid is much greater than that as a vapor, and the propellant estimate will probably be based on a gas storage state. If the storage tank liquid water quantity becomes significant, then

in high demand periods there will be the prospect of liquid water ingestion in the outlet flow and the chance of thruster flooding.

An interesting aspect of the liquid water problem is the throughflow of gas required to dry out the storage tank to nominal water content after liquid water has been deposited in the tank. If the input gas has a nominal dew point of 5°C and the tank and gas are at 27°C (dry bulb), the specific humidity is about 0.0028kg. water per kg of dry gas. Therefore, each kg. of nominal dry gas throughput can carry off the difference between this latter specific humidity and the saturation value (0.00785). The net drying effect is 0.005kg. water/kg. dry gas throughput. This converts to a throughput of 200 kg. of gas for each kg. of condensed water. This represents a month's production of Sabatier methane. Therefore, it appears that if water is condensed in the Sabatier output storage tank, it would be desirable to periodically drain the tank of liquid water residue to preclude the prospect of water blow-through. Another option would be to preheat the output prior to introduction to the thruster. For example, a preheat to 50°C before introduction to the thruster, would be sufficient to fully vaporize 2.5% by weight liquid water in the output gas above 50°C. The evaporative capacity of the gas increases exponentially and even small quantities of gas would be sufficient to carry-off any condensed water.

2.4.3 Combustible mixture hazards

One consideration in the selection of biowaste propellant supply and conditioning mechanizations is the presence of absence of a combustion hazard in the gas mixtures encountered. For example, the carbon-dioxide concentrator will desorb atmospheric oxygen and nitrogen with the carbon-dioxide, water and traces of nitrogen and perhaps hydrogen. A nominal set of effluent conditions is presented in Table 3.

TABLE 3

NOMINAL BIOWASTE COMPOSITION

Source	Composition		
	Species	Mole Fraction	Mass Fraction
CO_2 Concentrator	CO_2	0.984	0.989
	N_2	0.012	0.008
	O_2	0.004	0.003
Sabatier	CH_4	0.917	0.832
	CO_2	0.054	0.133
	N_2	0.014	0.020
	H_2O	0.015	0.015

If the potentially combustible Sabatier outputs are permitted to mix with an oxidizing environment, a serious hazard could be generated. To study this effect and predict any design constraints on the propellant conditioning system, the flammability limits of methane-air mixtures were studied.

The first criteria to be studied was the auto-ignition temperature of methane containing gas mixtures. Reference 1 indicates

that methane-air mixtures auto-ignite, if in combustible proportions, at approximately 540°C. Therefore, it appears that auto-ignition, i. e. ignition in the absence of a spark or other source,will not occur in the resistojet propulsion system even if a large quantities of air are entrained in the products since the supply system does not attain this level of temperature.

The second feature to be examined was the flammability limits of methane-air mixtures. Data from the reference Bureau of Mines Bulletin* indicates that for the range of pressures experienced in the resistojet propulsion system, i.e. 1-20 atmosphere, the effect of pressure on these limits is only of the order of a 10% influence. For simplicity, all analyses were conducted at 1 atmosphere pressure. One aspect of methane combustion is the lower gas temperature limit, below which combustion cannot be propagated. For methane in air, this is - 187°C. The latter limit indicates that at the ambient temperature experienced in the space station, i.e. 15 - 40°C, combustion is a possibility provided that appropriate mixture are encountered.

If the Sabatier outputs and the carbon-dioxide concentrator outputs are mixed and stored, then methane and oxygen will be

* Bull, 627 U.S. Department of Interior, Bureau of Mines, M. G. Zabetakis "Flammability Characteristics of Combustible Gases & Vapors" 1965.

present in the mixture. The possible mixture combinations were examined to determine if a combustion hazard could ever exist. Using Reference 1 again, and assuming that the mixture is one of air, methane and carbon-dioxide, the result is that mixtures in excess of 20 mole percent carbon-dioxide are not combustible for any proportions of methane and air. Therefore, for the nominal operation of the Sabatier and the carbon-dioxide concentrator, combustible mixtures are not possible since the air content of the Sabatier output is only about 1.6 percent air and the carbon-dioxide carry-over would be more than enough to suppress combustion.

Leakage of cabin air into the Sabatier output storage reservior could generate a combustion hazard. At 25°C methane-air mixtures are flammable in the range of methane mole-fractions from 5 to 15 percent. Therefore, only a substantial air leak would create a combustion hazard. To avoid this prospect, the Sabatier should be operated at slightly above ambient pressure such that leakage is outward from the reactor. Any such outward leakage should be to a well ventilated compartment or to space so as to minimize any cabin flammability problems.

2.4.4 Water vaporizer filtration

One component of the propellant conditioning system which would be prone to contaminant effects is the water vaporizer. The spacecraft potable water supply standard permits significant

solids in the water which may be used as a supplemental propellant in high demand periods. The Space Science Board water standard allows up to 1000 ppm of dissolved solids. At the point in the propulsion system where vaporization takes place, which may be the vaporizer or the thruster if there is no vaporizer, the dissolved solids will precipitate.

These solids will either accumulate or be transported as particulates into downstream parts of the system. Each thruster of .22N (50m lb) thrust passes 0.1 gm/sec of biowaste when operating. If this biowaste is marginally potable water, then 10^{-4} gm/sec of dissolved solids will be deposited or transported through the propulsion system during the period of water usage. At peak biowaste propellant demand, the daily water usage would be approximately 2 kg/day, which is a total contaminant load on the vaporizer(s) of 2 gm/day. This is an upper limit since the water may not contain the maximum contaminants and the supplemental demand is only made when the orientation orbit altitude and upper atmosphere properties and near the extremes of their possible ranges.

Once deposited, the contaminants could still be flaked-off by fluid forces or thermal expansions/contractions to create downstream particulate accumulation. Flow valve seats would be particularly prone to problems with deposits since the trend is to hard

seats and low seat loading pressures for temperature and electric power accommodation respectively. The 2 gm/day particulate load would have to be trapped by filter elements, or be otherwise contained in the vaporizer. The size of the particulate material generated cannot be estimated because it will depend upon such features as the cleanliness of surfaces, crystal grain growth, temperature, etc. The use of water supplement for long periods of time during the mission will require filter capacity of up to a few kg (200 days usage). Any vaporizer designed should accommodate the contaminant accumulation. Any extended surface vaporizer such as a packed bed of pellets must have sufficient void volume and over-capacity with respect to heat transfer to accommodate the contaminant build-up. In many respects this problem is similar to that of conventional boiler scale except that the small size of the resistojet flow passages accentuates the magnitude of the problem.

Particulate material passing through the resistojet system and into the resistojet exhaust plume could cause several types of problems. The particulate material could create false sensor readings on optical instruments which measure in the wave length regime common to the particle size or smaller. The use of high temperature resistojets would also raise the prospect of ionized exhaust particles, i.e. alkali-metal salts. The latter could cause electromagnetic transmission interference in discrete bandwidths.

The alternative to incorporating a separate vaporizer is that the use of a vaporizer in the thruster assembly be studied before a decision can be made. A firm decision cannot be made until the development test on vaporizing thrusters is complete. If the particulate matter accumulates in the thruster to degrade flow and heat transfer, then periodic replacement will be required. At 400 gms. of deposit per 1000 hours of operation per 0.22 N(50m lb) thruster it would appear that thruster replacement for contaminant build-up reasons would exceed the replacement rate due to functional failure during the water supplement operating period. Mean time-to-failure of the order of 10,000 hours is a performance target of the thruster, exclusive of the potential contamination problem noted. If the material passes through the thruster into the plume, then the external contamination effects may dictate an upstream filter to accumulate the residues passing through the vaporizer.

In summary, the choice of a separate vaporizer requires that the design incorporate an adequate filter and residue chamber with scheduled replacement. Vaporization integral within the thruster creates one or another potential problem either contaminants accumulate and frequent replacement of thrusters is required or else the contaminants carry through to increase exhaust plume problems.

2.5 Simulation trade studies (Task 3.5)

The execution of ground-based development tests of the biowaste resistojet propulsion system requires the simulation of typical flight application constraints. One of these is the use of simulated gases representing actual biowaste compositions. Use of these simulant gases will exercise the propellant system with respect to contaminant tolerance and any influence of chemical reactions with the trace constituents in long-life demonstration tests. Several options can be considered; use of actual biowaste gases, use of premixed gas mixtures, or on-site mixing of traces into pure constitutents. Use of actual biowaste gases is the most desirable, but requires that simultaneous tests of an EC/LS system be underway to provide a source. Also the logistics of collecting and transferring the gas from the EC/LS test to the resistojet test could present problems in schedule and convenience. The other two options were examined in some detail to determine their relative advantages and disadvantages. A common simulation problem for any option is that the flight system will see an infinite variation of the EC/LS mechanizations outputs. Therefore, any practical ground-tests will be limited to the extremes of ranges of the mixture parameters and some of the small traces or infrequent situations will probably not be simulated well.

The objective of the work conducted under this task was to examine the options available to simulate contaminant levels in the nominal biowaste gases to provide an adequate but practical ground test program.

To make an overall system cost comparison, it was necessary to define the flow streams that would be required. Flow streams were re-defined in adequate detail to reflect the state of knowledge of overall contaminants. Flow Stream 1 represents the McDonnell Douglas envisioned stream from a tap downstream of the Sabatier when the system is working normally. Flow Stream 2 is the McDonnell Douglas concept of products when the Sabatier is off-the-line. The tap is upstream of the Sabatier. Flow Stream 3 represents the stream downstream of the Sabatier for the North American concept including hydrogen supplement and Flow Stream 4 is the supplemental propellant constituted from the excess water which accumulates from the life support loop. The tables define the stream constituents of Table 4.

Earlier studies under this contract identified trace contaminants which were found in cold trap effluent from the carbon-dioxide separater during the NASA 90-day manned test at McDonnell Douglas. This contaminant array was examined for its potential to create problems as a result of chemical activity and concentration. Six substances were selected which range in concentration from 10 parts per million to a tenth of a part per million and are

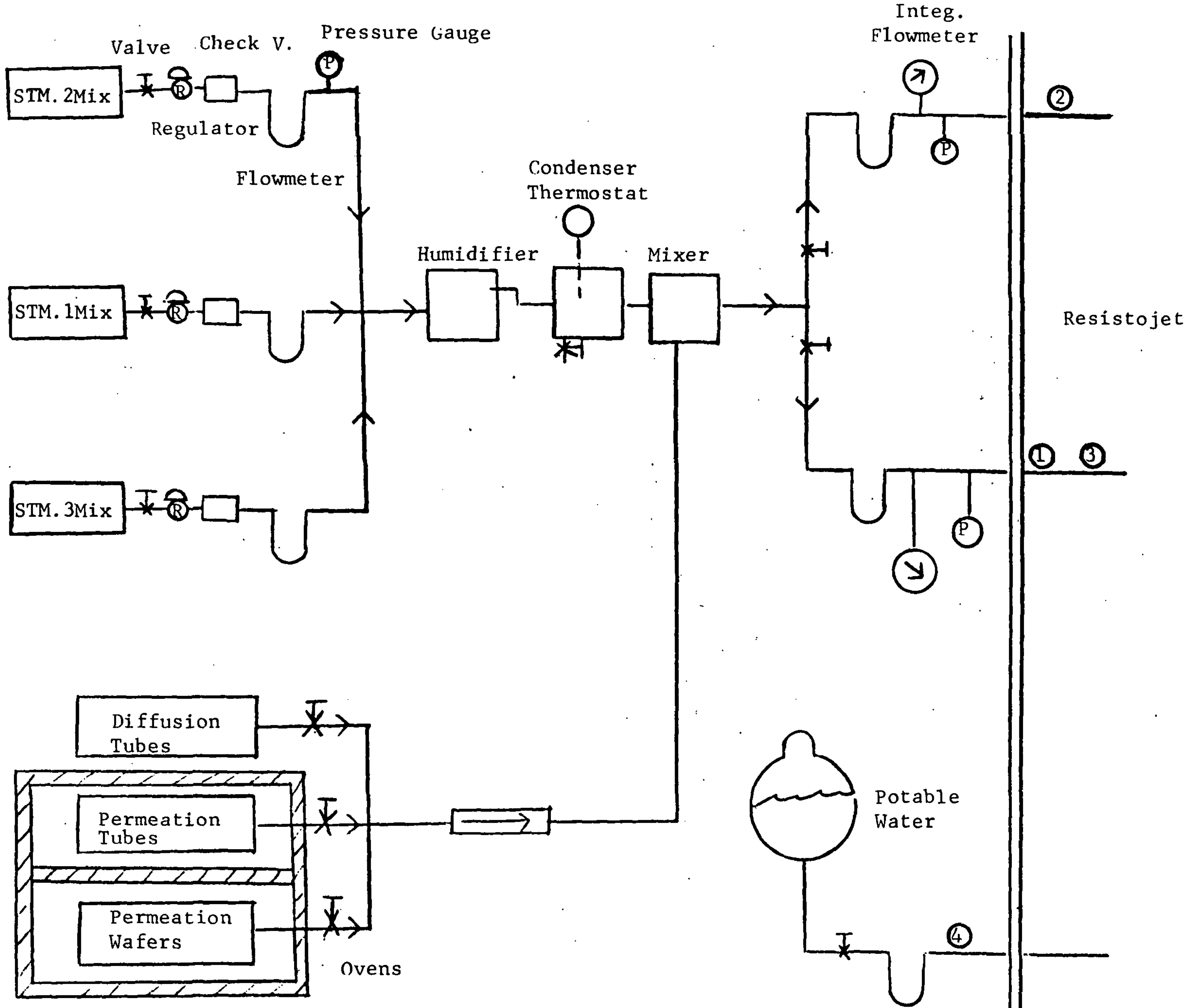
listed in Table 5, "Trace Array of Flow Streams 1, 2 and 3".

It was determined that trace contaminant generators are commerically available to produce and control these trace contaminants. By sealing small amounts of contaminants in teflon tubes, or tubes with teflon wafer inserts, variation over many orders of magnitude of production rate can be achieved. The rate is controlled by selection of the size of vessel, and operating temperature. Transmission lines should be small diameter and of short length in order to ensure minimal lag in the delivery of contaminants to the mixing chamber. System price goes up rapidly with specification of stringent control of production rates. If precise control of rates is desired, temperature control must be held to within a tenth of a degree centigrade. This, in turn, requires sophisticated ovens and substantially increased cost. However, since the resistojet test is of long duration and since the production rates in an actual spacecraft will be highly variable and non-predictable, it is recommended that temperature be only approximately controlled, and direct determination of the resultant rates be determined every several days by simply weighing the generation source. This will give the integrated quantity of that particular trace which has been introduced into the system for the period of time since the last weight measurement.

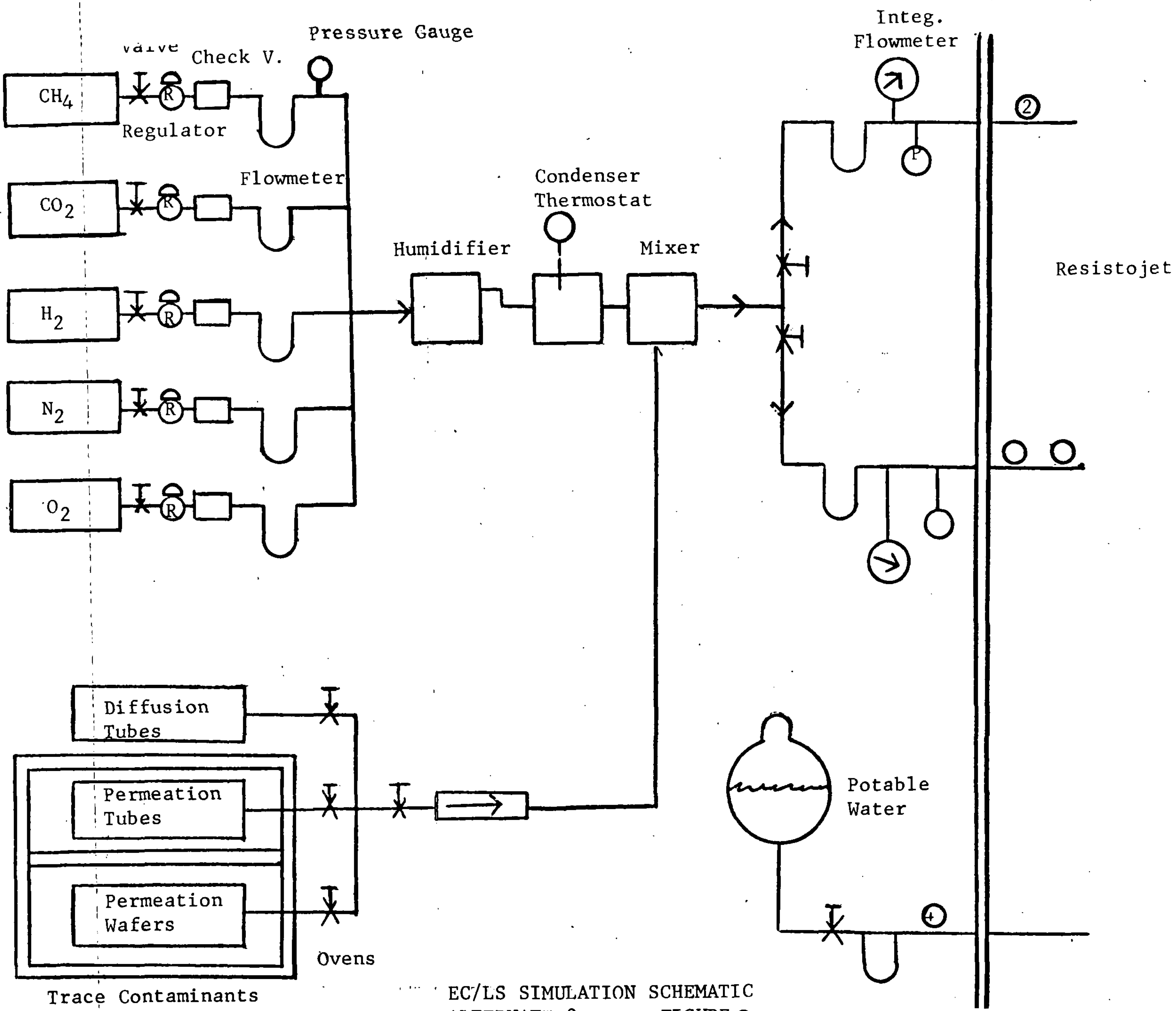
With the exception of the Sabatier, it was assumed that the life support system would operate as designed and specified. The

Sabatier system being relatively new, it is expected to experience periods of down time and this is the rationale for Flow Stream 2. Potential contaminants produced by off-design performance of the Sabatier were considered. It was determined that there is little chance of contaminants being contributed by the Sabatier. Neither excess carbon-dioxide nor excess hydrogen appear to contaminate this reaction as such. If for some reason the desired reaction temperature of about 550°C is decreased, the reaction is extinguished and the reactants passed through without change. If the temperature of reactor increases substantially above the nominal, it is possible to produce carbon and hydrocarbons in the alkaline series. However, since there is no source of thermal energy in the reactor except the exothermic reaction itself and the heating element which initially heats the reactor to commence the normal reaction, it is considered highly unlikely that the complications of over-temperature operation would be experienced in flight.

In order to examine partial simulation, a cost trade-off was conducted examining two alternates for supply of propellant gas and contaminants. Alternate 1 is seen in Figure 7. Using premixed gases, one array of bottles is required for each of the three gas-mixtures. A humidifier and condenser control the gas dew point. A mixing chamber is provided to ensure homogeneity of the very small amounts of trace contaminants which are provided from the diffusion system. Flow meters would be inserted



EC/LS SIMULATION SCHEMATIC
ALTERNATE 1 FIGURE 7



EC/LS SIMULATION SCHEMATIC
ALTERNATE 2 FIGURE 8

in most streams so that by direct observation or by deduction, flow rates of the nominal supplies and the contaminants can be observed and controlled. Integrating flow meters (gas metering) will total the flow over some specified times such as 24 hours, as a check on flowmeter settings. Check valves will be inserted in the lines to avoid any back flow and contamination problems. Adequate pressure instrumentation must be inserted to provide information for adjustment of observed flow rate values. Pressure regulators and valves are required to adjust and balance and control flow from the various bottles. Water for the propellant supplement system would be provided from a commercial flask.

In the concept of Alternate 2, Figure 8 , individual gases, methane, carbon dioxide, hydrogen, nitrogen and oxygen are acquired commercially and mixing is done by control of pressure and flow rates in the individual branches of the system. Other than the increase in flow control equipment required because of the greater number of bottles, there is no difference in the flow hardware.

Total cost for Alternates 1 and 2 are found in Table 6. Expendable cost excede hardware cost by an order of magnitude for Alternate 1. A savings in expendables is achieved in Alternate 2 by supplying of individual gases in their own separate containers. Not only are these more readily available on a production basis from industry, but it is possible to supply the individual gases at optimum pressures. For example, carbon dioxide supplied in a

mixture must be at a pressure low enough to ensure condensation, and phase separation does not occur during shipping. If this were not achieved, a container could be tapped and used wherein a substantial portion of the carbon dioxide is in the liquid form. During initial delivery the flow would be relatively rich in the other gases present in the bottle and by the end of the delivery period of that bottle, it would be relatively rich in carbon dioxide as the liquid finally boiled back into gaseous form. The other reason for a higher cost of expendables in Alternate 1 is that specifying four-component mixtures increases supplier quality control costs. This is particularly true if there is a strict specification on the quality of the stream. Certification also increases costs.

Alternate 2 will not require a significantly greater amount of labor to operate than Alternate 1. This is achieved by determining the endurance of a bottle of each specie and providing a bank of bottles in adequate quantity to last through the period of no attention, say 24 hours. Regulator delivery pressure from individual bottles is set to cascade so that one bottle is essentially exhausted before a second of that bank automatically commences supplying gas. At that point the exhausted bottle can be disconnected from the bank and a fresh bottle installed, without interrupting delivery, or all expended bottles are replaced each 24 hours. The acquisition of gases species by species also permits changes in the desired mixture ratio or quality just prior to, and during the

test program. More detail on the generation of trace loaded gas mixtures is presented in the reference paper* describing the apparatus.

During system designs a detailed analysis of safety considerations must be conducted. Flow stream 3 calls for a nominal 76% methane and 20% hydrogen with traces of nitrogen and water vapor, a trace array, and 1% oxygen. Commerical sources indicate that the 1% oxygen represents an upper limit for safety with 20% hydrogen present. This must be kept in mind when mixing gases in the laboratory and interlocks must be provided to insure that oxygen supply maximum pressure is interlocked with hydrogen supply pressure, or in some other manner oxygen supply rate is controlled. Hydrogen embrittlement is not only a consideration in demonstrating feasibility on the resistojet system but must be considered in terms of safety in the laboratory.

The primary objective of simulation of the biowaste gases is to subject the thruster and other flow components to a representative environment. Therefore, all constituents which could contribute to anomalous performance of the system should be included if practical. The principal gaseous trace constituents are oxygen, hydrogen, and water vapor, since at elevated temperatures each of these had in the past constituted a metallurgical compatibility test. Of the other

*Martin, A. J. and Debbrecht, F. J. "Devices for Preparing Low-Level Gas Mixtures", Analytical Instrument Development, Inc., West Chester, Pa.

constitutents, the most important to the thruster are probably the traces of inter-halogen compounds such as the Freons. At resistojet operating temperature these compounds dissociate into active flourine and chlorine groups which would be a challenge to most materials at the upper-end of the resistojet thruster operating temperature range. Routine use of these traces is not required for check-out testing of the propellant systems since internal temperatures are not high enough to dissociate the stable forms of the inter-halogen compounds. An important feature of the gaseous forms of contaminants is whether they represent a potential for acid generation in the presence of water in the storage reservoir. If so, then corrosion internal to the plumbing system would be prospect. At present there does not appear to be any sulphourous or chlorine compounds which would generate such problems.

The influence of contaminant traces in the water is another problem of simulation. Since the vaporizer, either internal to the thruster or external, is a new technology component this aspect should be fully explored in the development tests through contaminant simulation. The residue build-up, possible transport and exhaust are important features of the feasibility demonstrations of the systems. The prior discussion of the water contaminant levels and options of sources has presented the array of contaminants present in the water.

TABLE 4

FLOW STREAM CONSTITUENTS

All at 14.7 psia, 70°F

STREAM 1 - 0.75#/hr.
0.65#/hr. to 0.96#/hr. over 60 minute period

Nominal	% (by Volume)
CH_4	56
CO_2	41
Contaminants	
N_2	1
O_2	1
H_2O	1
Trace Array (See Table B)	-

STREAM 2 - 1.2#/hr.
1.02#/hr. to 1.51#/hr. over 60 minute period

Nominal	% (by Volume)
CO_2	97
Contaminants	
N_2	1
O_2	1
H_2O	1
Trace Array	-

STREAM 3 - 0.43#/hr.
0.38#3hr. to 0.48#/hr.

Nominal	% (by Volume)
CH_4	75.6
Contaminants	
H_2	19.9
N_2	3
O_2	1
H_2O	0.5
Trace Array	-

TABLE 4 cont.

STREAM 4 - 16.#/hr.
Storage capacity required: 1 gallon

Nominal	
H_2O, liquid	
Contaminants	
Arsenic	0.50
Barium	2.00
Boron	5.00
Cadmium	0.50
Chloride	450.00
Chromium	0.05
Copper	3.00
Fluorine	2.00
Lead	0.20
Nitrate	10.00
Selenium	0.05
Silver	0.05
Sulfate	250.00
Chem. Oxygen demand (COD)	100

TABLE 5

TRACE ARRAY*

FOR FLOW STREAMS 1, 2, 3

Constituent	Concentration, Parts per Million
Acetone	10
Acetaldehyde	1
Dimethylsulfide	0.5
Ethylalcohol	0.1
Methylenechloride	0.1
1 - Butene	0.1

Tolerance: 50%

TABLE 6

SYSTEM COST (Totals Approximate)

Alternate 1

Item	Quantity	Unit Cost	Cost
Flow Meters	9	$ 60	$540
Valves	9	10	90
Regulators	9	40	360
Check Valves	7	10	70
Flowmeter, intergrating	2	100	200
Pressure Gages	11	30	330
Humidifier	1	50	50
Condenser	1	100	100
Mixing Chamber	1	30	30
Tubing, misc. mat'ls	-	70	70
Trace Contaminants - ovens	3	750	2250
TOTAL, Hardware			$4100

EXPENDABLES (1 Year Supply)

Gas-stm 1 mix.	392 bottles	$70/b	$27,400
Gas-stm 2 mix.	650 "	70/b	45,500
Gas-stm 3 mix.	234 bottles	70/b	16,300
Water	14,000 #	$.07/#	1,000
Trace contaminants Generator tubes, wafers	6	30	100
TOTAL, Expendables			$90,400
TOTAL COST, Alternate 1			$94,500

TABLE 6 (cont.)

SYSTEM COST APPROXIMATION

Alternate 2

Item	Quantity	Unit Cost	Cost
Flow meters	12	$ 60	$720
Valves	12	10	120
Regulators	12	40	480
Check Valves	10	10	100
Flowmeter, integrating	2	100	200
Pressure gages	14	30	420
Humidifier	1	50	50
Condenser	1	100	100
Mixing Chamber	1	30	30
Tubing, misc., mat'ls	-	100	100
Trace contaminants - ovens	3	750	2250
TOTAL, Hardware			$ 4570

EXPENDABLES (1 Year Supply)

Gas, bottled			
CH_4	6620#	$ 3.36	20,900
CO_2	13100	.22	2,880
H_2	754	14.80	11,100
N_2	283	.465	110
O_2	210	.415	90
TOTAL, Expendables			$36,340
TOTAL COST, Alternate 2			$40,800

For Flow Streams 1, 2, and 3 (See Tables 4 and 5), which are the gaseous propellant supplies from the EC/LS to the resistojet, it is recommended that propellant and contaminants be purchases as individual gases, with the exception of water. Humidification of the process stream to the desired level can be satisfactorily achieved through preparation in the laboratory. Trace contaminants can also be added in the laboratory by the control and operation of diffusion tubes, permeation tubes and permeation wafers. These latter items are commercially available, and the mass output rate can be controlled. Water for Flow Stream 4 (See Table 2) would be purchased commercially or derived from NASA R & D tests of contaminants equal to the maximum potable levels set by the Space Science Board of the National Academy of Sciences.

The entire system cost for this approach would be $40,800 for a total of a year's operation of all four streams, at nominal flow rates. Amount and cost of expendables required for trace contamination is negligible. However, the quantities of propellant gases are substantial.

The objective of the test to simulate biowaste gas compositions could still be achieved by the recycling of a significant portion of the gases back to the EC/LS - simulated source by a lab pump. The propellant conditioner system could be exercised but instead of operating an array of thrusters, up to 32, only 4-6 would be operated. Thruster life, as a result of propellant contamination, could still be determined by this method. Flow over and above

what was required for demonstration thruster dump could then be recycled back to the propellant supply system.

2.6 Functional Analysis Plan (Task 3.6)

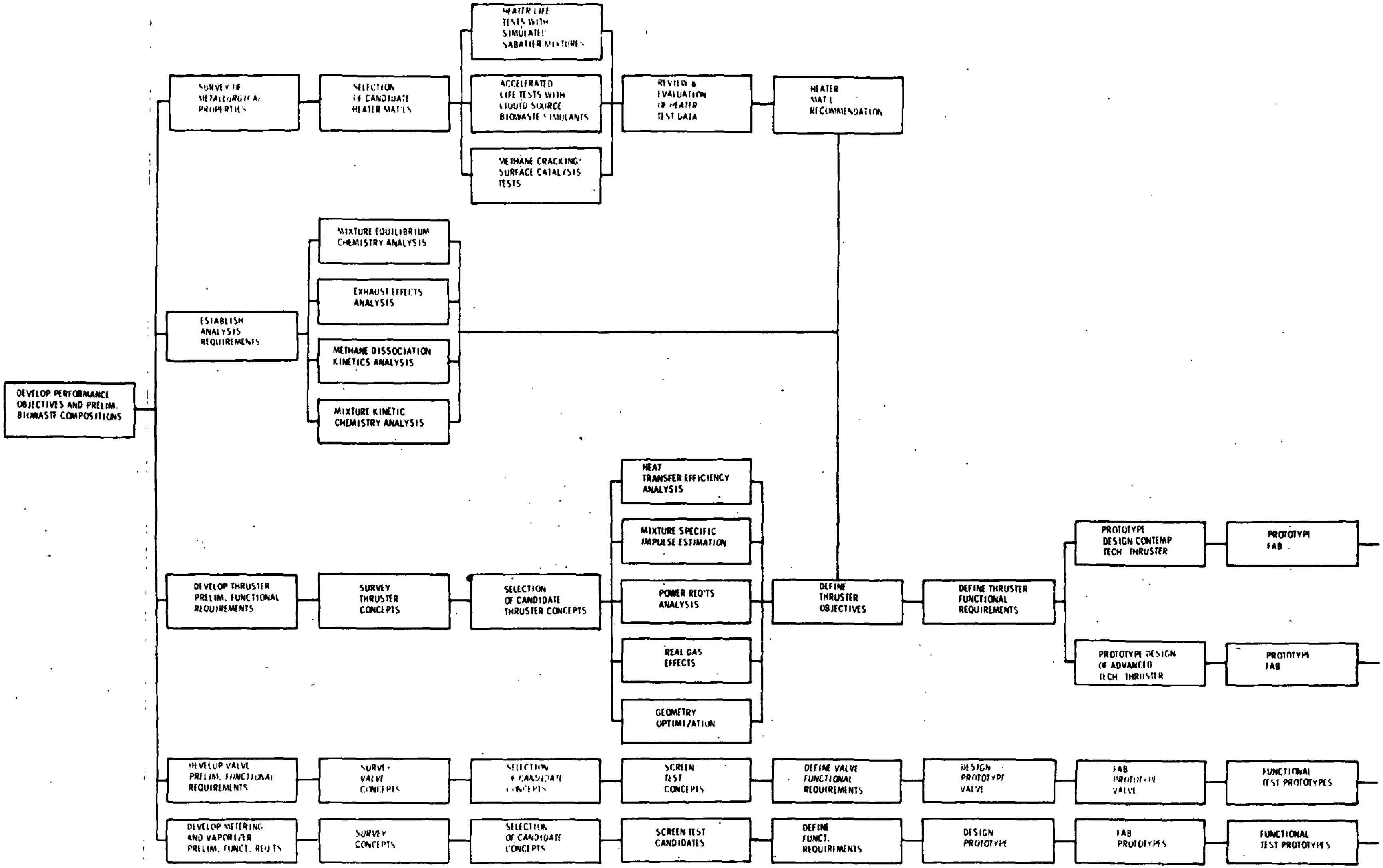
The functional analysis serves to identify the principal study, development and interface elements of a biowaste resistojet program from concept formulation to flight status. Such a plan is particularly useful in the biowaste resistojet program because of the requirement that this system be fully integrated into the manned spacecraft. The conventional propulsion interfaces with the guidance-control function are complicated by the variability of demand which can be exhibited throughout a ten-year mission in the various vehicle orientation modes which are anticipated. The interfaces of the propulsion system with the EC/LS systems are both novel and complex since biowaste supplies are highly variable in composition and optional sources may be laden with contaminating constituents which are detrimental to the biowaste propulsion system life or functional performance. The functional analysis can identify the areas of potential future problems and define the sequence of studies, tests and specifications which ideally should be provided to preclude program impacts downstream.

A single chart containing all of the elements was found to be too unwieldy to extract information of specific concern, such

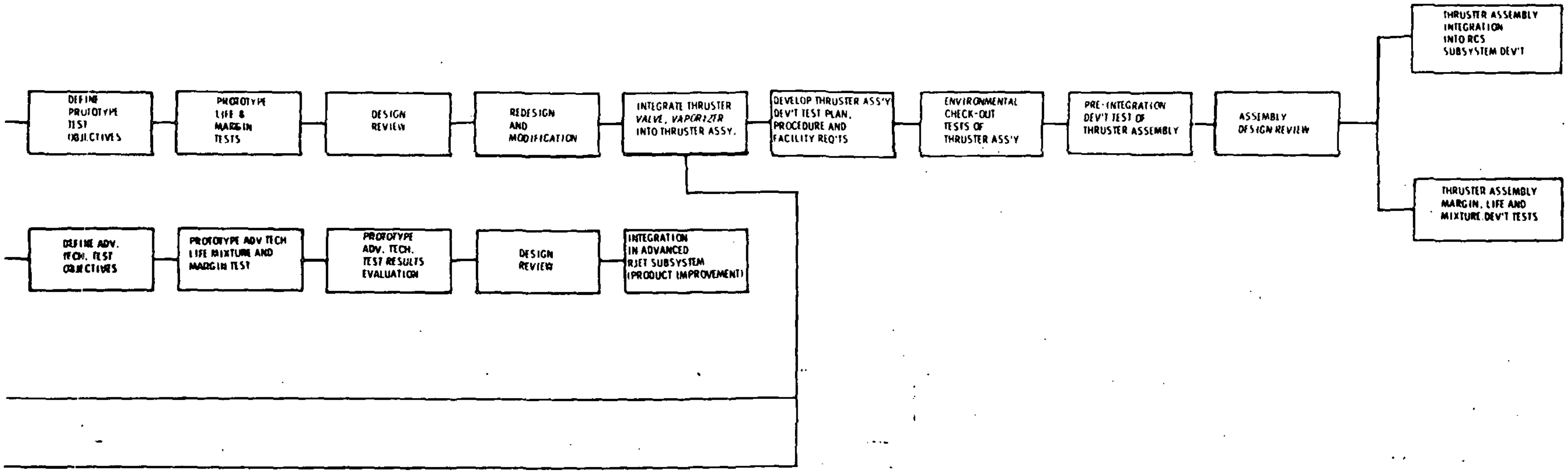
as for the thruster. Therefore, the biowaste resistojet subsystem was divided into its major subassemblies for detail evaluation. The thruster, valve, propellant conditioner, and control logic/power assembly were obvious divisions. A new subassembly quantity gaging, is introduced from the event that biowaste composition variation is shown to be significant. The event flow, once the assemblies are married into a subsystem, was shown separately to emphasize the over-all subsystem interactions that must be accommodated. The EC/LS propulsion interfaces are separable entities which would be of specific value when the biowaste resistojet subsystem must be integrated with the EC/LS disciplines. Similarly the interfaces with possible experiment sources are treated separately. The resistojet propulsion system integration events with the over-all Station/Base development is another area of only top-tier concern which does not require complete explicitness of either assembly or subsystem interaction details. Figures 9-11 are typical of the results presented in comprehensive detail in the second monthly progress report.

2.7 Propellant system development plan

The results of the prior work under the contract were used to describe the functional requirements and a possible implementation plan for a propellant collection, control, and power conditioning mechanization for the biowaste resistojet. The implementation described is that required to provide the Government with a prototype ground-test system for use in feasibility demonstration tests

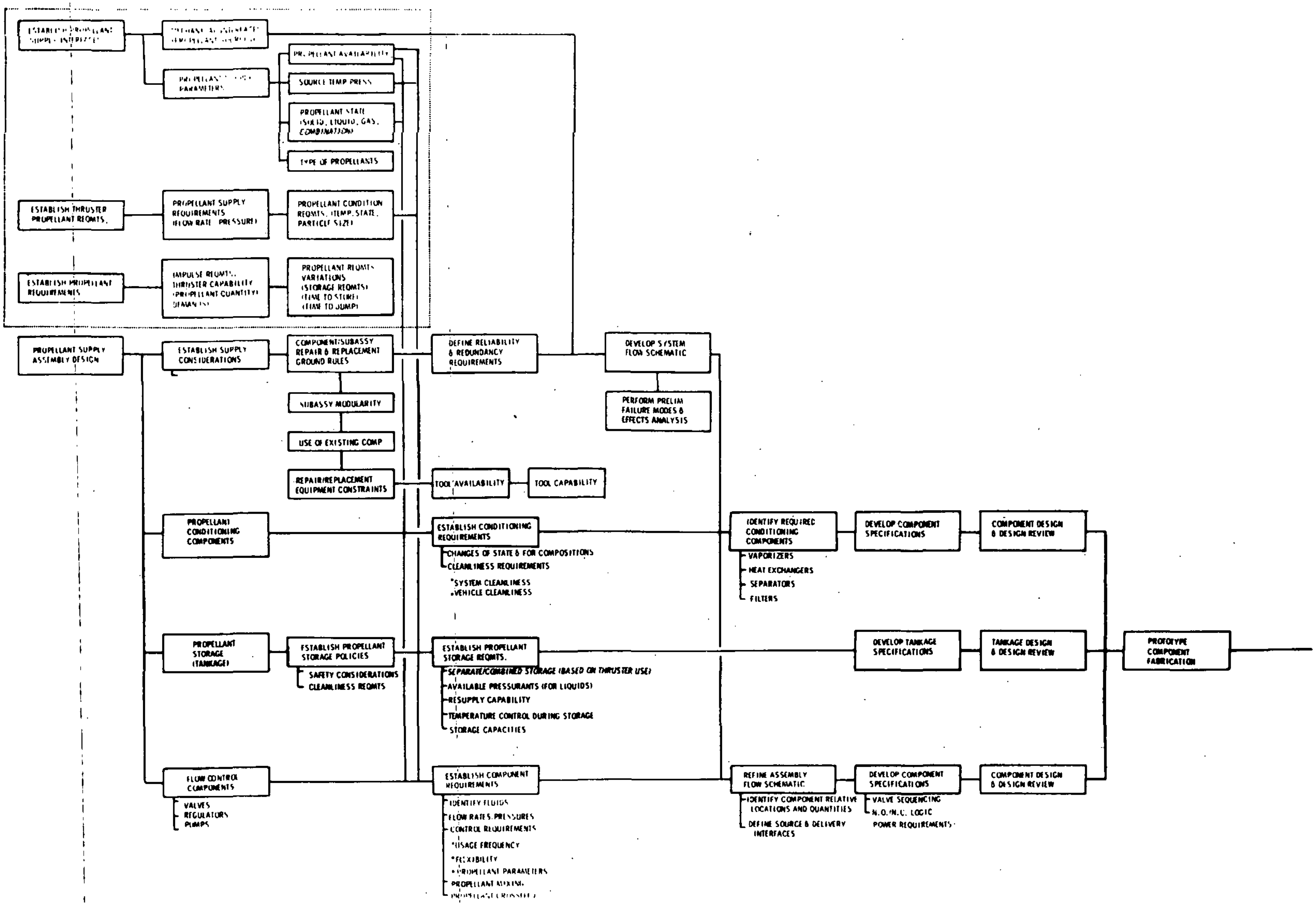


THRUSTER ASSEMBLY
Figure 9-A



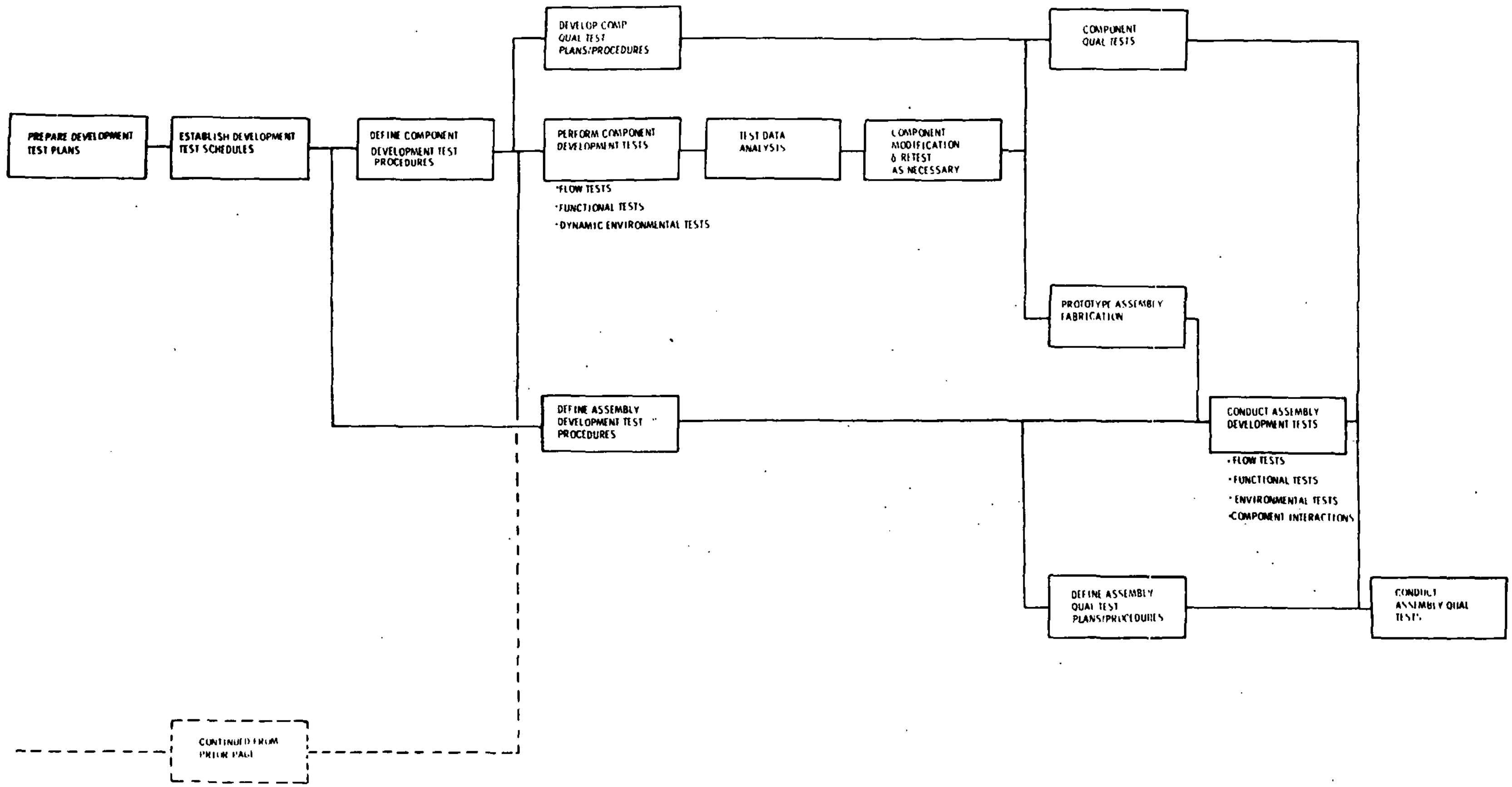
THRUSTER ASSEMBLY (CONT'D)

Figure 9-B



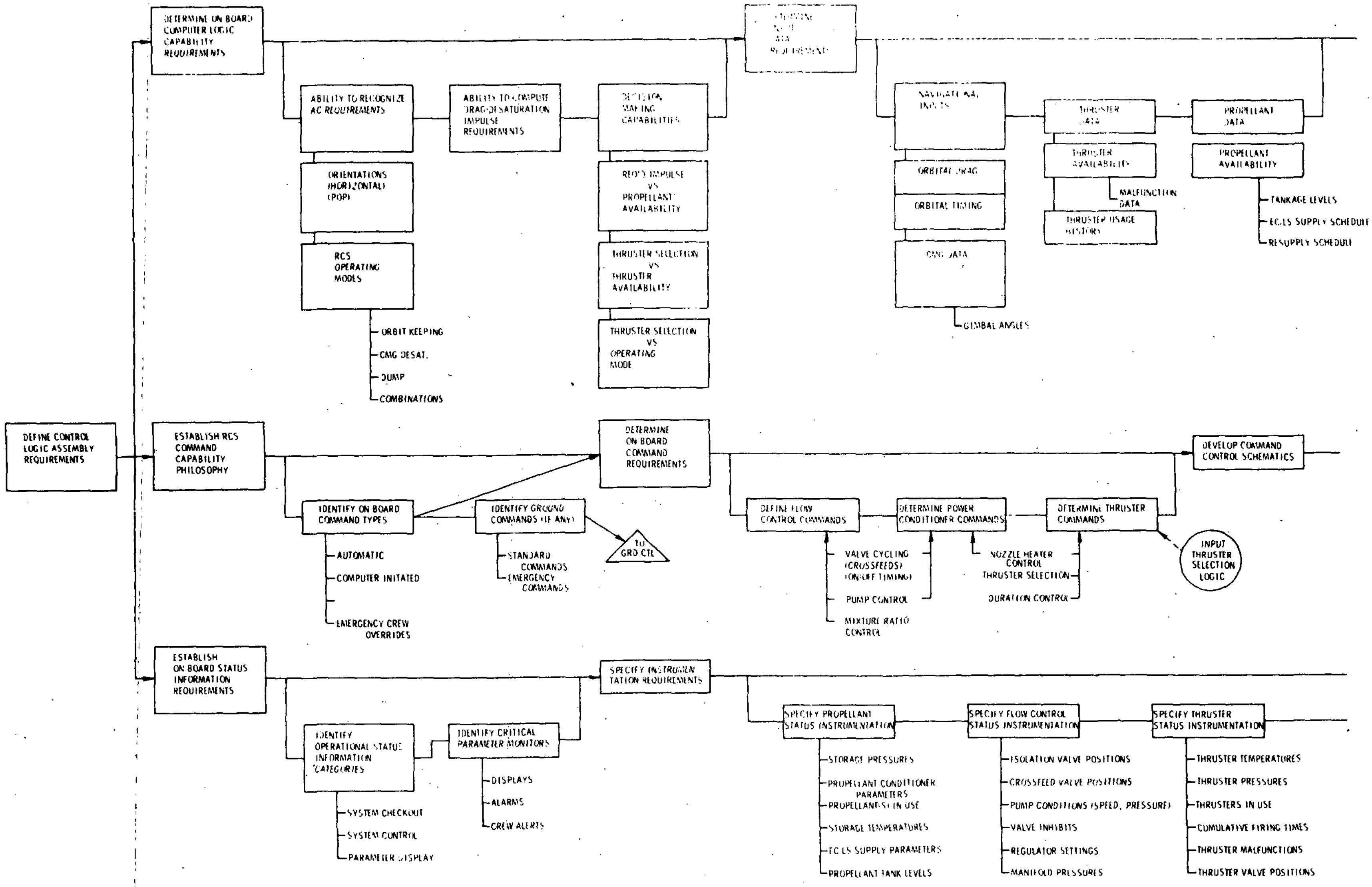
PROPELLANT CONDITIONER ASSEMBLY

Figure 10-A



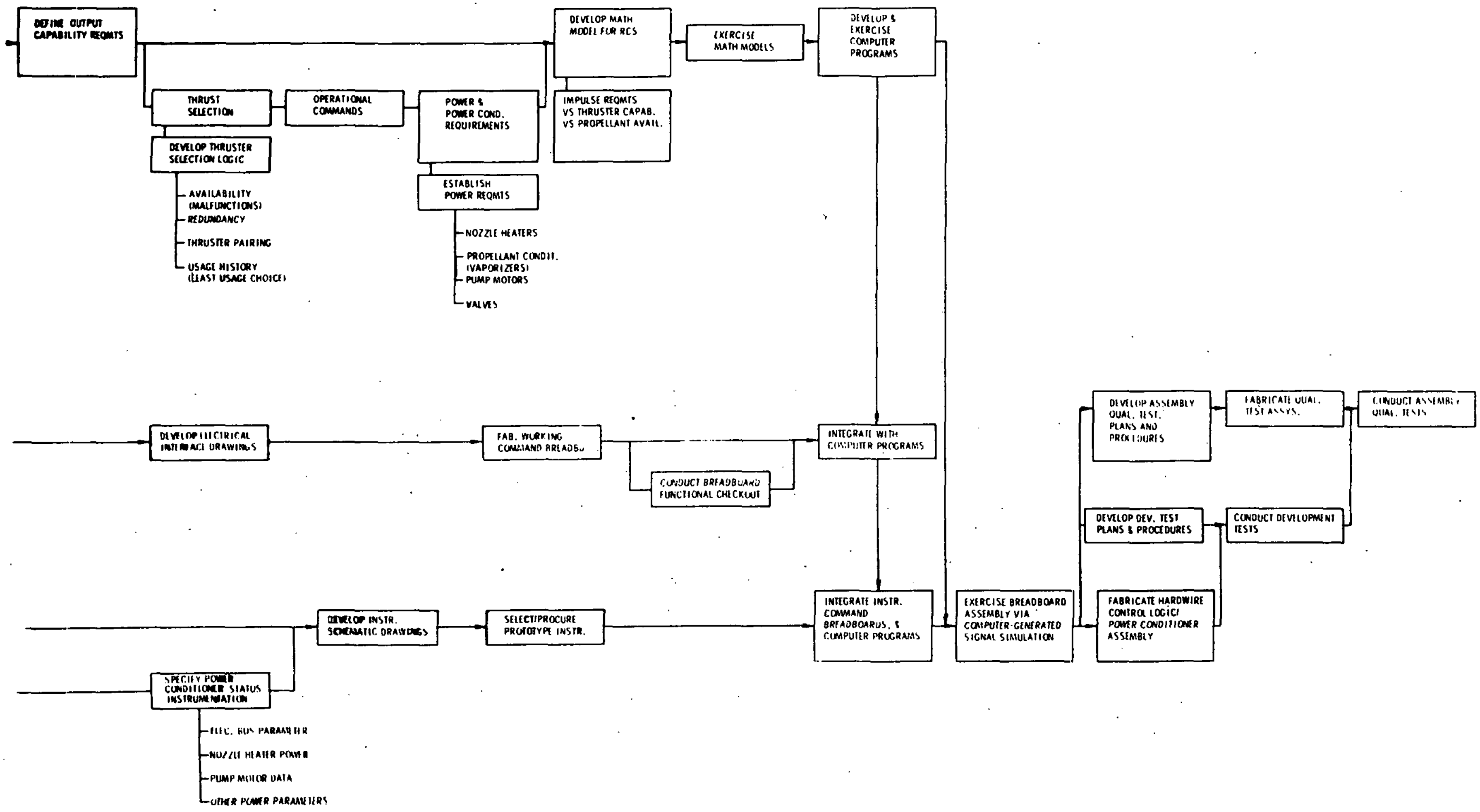
PROPELLANT CONDITIONER ASSEMBLY (CONT'D)

Figure 10-B



LOGIC AND POWER ASSEMBLY

Figure 11-A



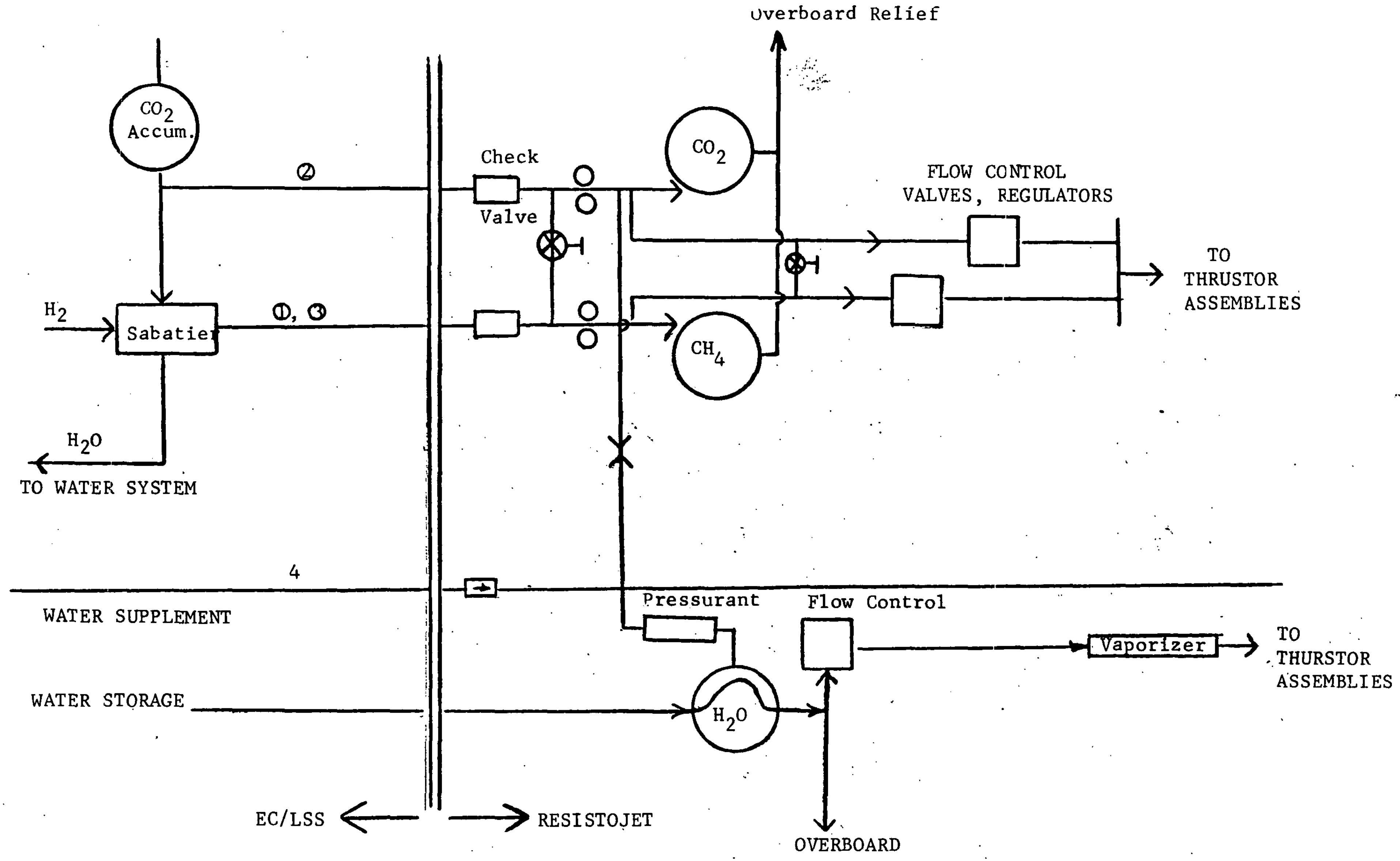
LOGIC AND POWER ASSEMBLY (CONT'D)
Figure 11-B

at NASA-Langley Research Center, using Government supplied thrusters and facilities. This portion of the contract work describes the technology requirements of hardware and software elements of the propellant conditioner and control system.

2.7.1 System functional requirements

The propellant collection and control mechanization for a biowaste resistojet propulsion system has been studied at the preliminary design level in prior and contemporary contract efforts, i.e. NAS1-10127, NAS1-10170. The purpose of the current work was to incorporate these results with the requirements derived from the contamination studies and interface definitions into a system functional requirements outline. From this outline of requirements, it is possible to derive the advanced development effort required to provide a representative.

Figure 12 illustrates a candidate Biowaste Resistojet Propulsion System Schematic. Accepting the biowastes of CO_2, CH_4 and H_2O, from an EC/LS system, including any associated contaminants, the propellant system will store CO_2 and CH_4 separately for use as propellant in resistojet thruster assemblies. Accepting stabilization and translation impulse requirements, which call for intermittent firing sequences, the system logic takes the quantity of propellant in storage and other information into account, calculates impulse performance and commands the system, including the thrusters, for optimum system operation.



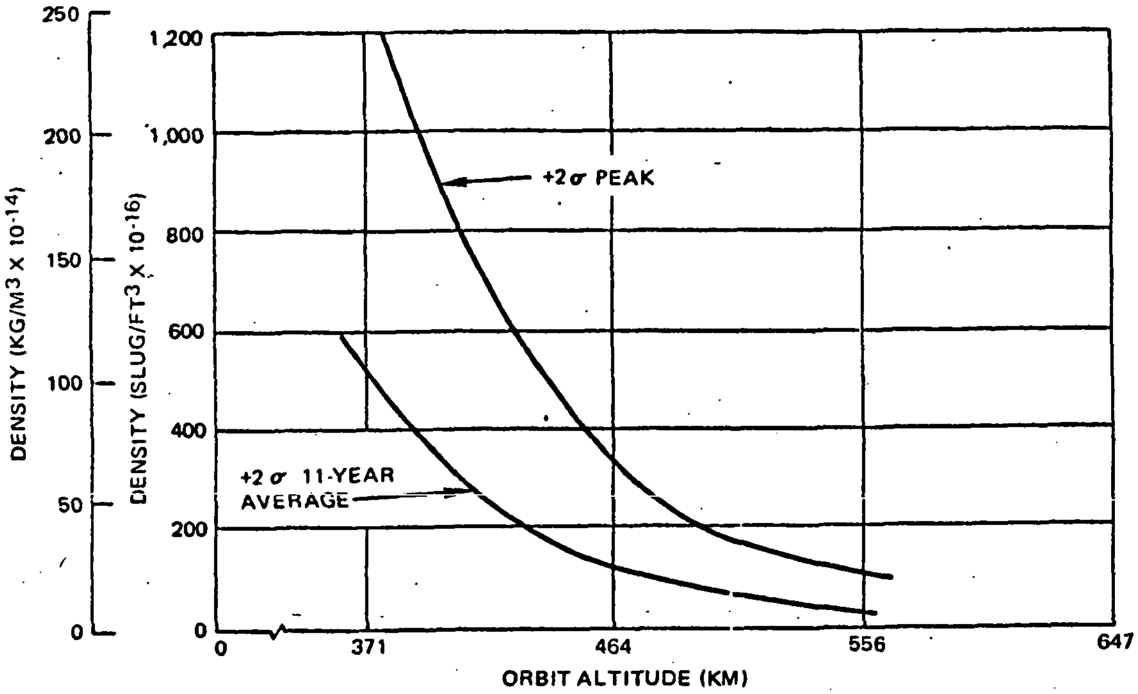
NOTES: Schematic typical. Each assembly interconnected with others.
①, ②, etc. - Flow streams

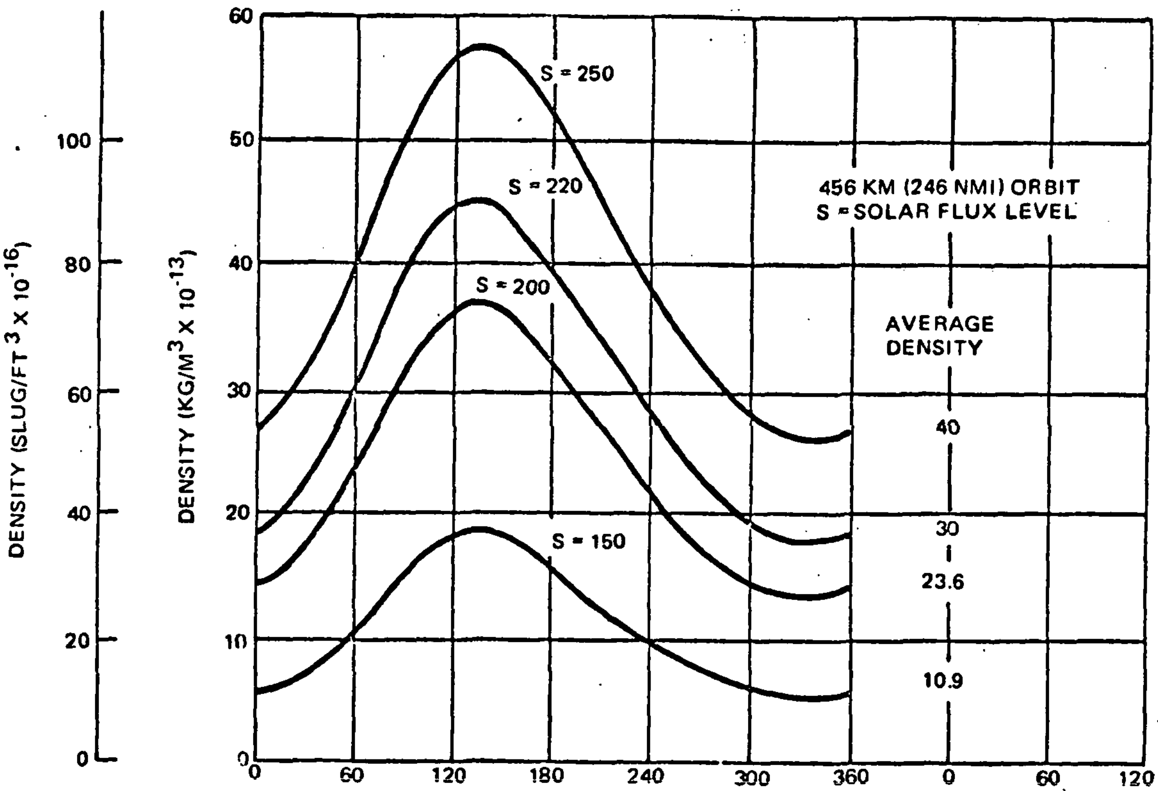
FIGURE 12 BIOWASTE SYSTEM SCHEMATIC

2.7.1.1 Impulse requirements

To estimate resistojet system operational requirements, a representative space station mission was examined. Present studies use a nominal orbital altitude of 245 n.m., but other altitudes are being considered, from 200 to 300 n.m. Various candidate missions of the space station require stabilization in such orientations as horizontal, perpendicular to the orbital plan (POP) and inertial. Continuous primary altitude control is performed by the control moment gyro (CMG), and corrects for both external and internal disturbances. An example of an internal disturbance might be crew movement. External moments are aerodynamic, due to offset of the center of mass from the center of pressure, changes in the physical properties of the system, such as addition of an experiment module, etc. In addition, because the space station is exposed to aerodynamic drag caused by the presence of a trace atmosphere, the space station orbit would decay to an unacceptable value without the application of translational thrust. The resistojet system provides the impulse to satisfy these two modes of impulse requirements, rotational and orbital

Several factors cause wide variation in ambient atmospheric density. It will vary, primarily due to altitude. Other factors also contribute to this variation such as changes in solar activity and lack of knowledge of atmosphere properties. Density will vary for angular position in any given orbit due to solar heating on the earth's day side, and lack of it on the night side. See Figures 13. These impulse requirements have been analyzed in Contract NAS1-10127. The results are shown in Table 7. Differences between maximum and





Atmosphere Density Profile

Atmospheric Density Variation
Figure 13

11-year average impulse requirements are caused by variation in density as a result of changing solar activity. Variation in orbit-keeping requirements which result from these requirements, is typified in Figure 14. See Figure 14. Note that for the horizontal orientation firing in one direction can satisfy both a yaw correction and orbit-keeping requirements, so the total impulse required is simply the greater of the two. For conservatism in approach, the flight system will be designed for the maximum orbit-keeping impulse required, 8,230,000 N-S/90 D and assume any form of angular correction may be required.

Note that impulse requirements near the peaks of the impulse demand profile, created by the 11-year solar cycle (which affects atmospheric density), will exceed that available from biowastes CO_2, CH_4. Additional propellant must be provided either by ground resupply, or exploitation of excess of water from the EC/LS (see below). Since water is easily stored, and would permit other utilization of that portion of shuttle payload which would be required to carry up propellant, it is reasonable to look to this source.

For a given required total impulse, thrust and duty cycle are adjustable. Since power is at a premium, its use shall be minimized, consistent with satisfaction of other requirements. For most operations an excess of propellant exists and it is possible to reduce required power input and increase mass flow. Single thruster usage is efficient thermodynamically. However, continuous use reduces reliability. A duty cycle of near 80% has been selected, at a single nozzle thrust of 0.11N (25 m lb) as a reasonable compromise.

Table 7

IMPULSE REQUIREMENTS SUMMARY

HORIZONTAL ORIENTATION

Low Thrust Impulse Functions	Orbit Altitude (km)			Comments
	371	456	556	
Orbit keeping (N-s/90 days)				
Maximum	2,640,000	748,000	209,000	The maximum drag configuration has four docked experiment modules
11-yr average	1,140,000	289,000	64,600	
CMG desaturation (N-s/90 days)				Control lever arm = 5.04 m altitude trim is used to eliminate the pitch propellant impulse requirements
Maximum				
Roll	0	0	0	
Pitch	0	0	0	
Yaw	67,200	19,100	5,300	
Total impulse (N-s/90 days)				Using aft firing thrusters, the orbit-keeping and CMG desaturation functions can be combined.
Maximum	2,640,000	748,000	209,000	
11-yr average	1,140,000	289,000	64,600	

Table 7 (cont'd)

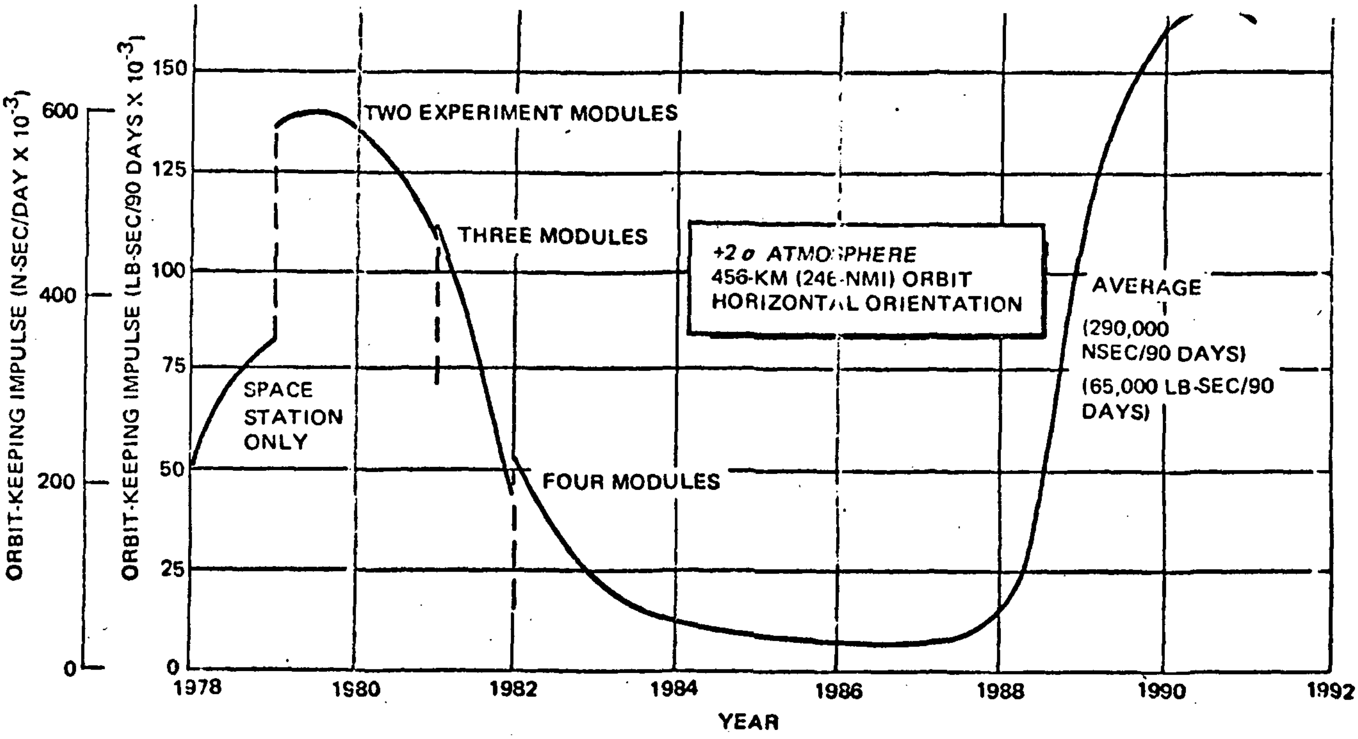
POP ORIENTATION

Low Thrust Impulse Functions	371	456	556	Comments
Orbit keeping (N-s/90 days)				Additional drag of four experiment modules is 20% of the total for the POP orientation
Maximum	8,230,000	1,070,000	298,000	
11-yr average	1,780,000	445,000	97,800	
CMG desaturation (N-s/90 days) (Control lever arm = 5.04 m)				
Maximum				Pitch and yaw desaturation impulse requirements are dependent on the diurnal bulge characteristics
Roll	0	0	0	
Pitch	445,000	129,000	35,600	
Yaw	445,000	129,000	35,600	
Total impulse (N-s/90 days)				Using radial thrusters on the 2-deck and the 4-deck modules, the orbit-keeping and desaturation impulse can be combined.
Maximum	8,230,000	1,070,000	298,000	
11-yr average	1,780,000	445,000	97,800	

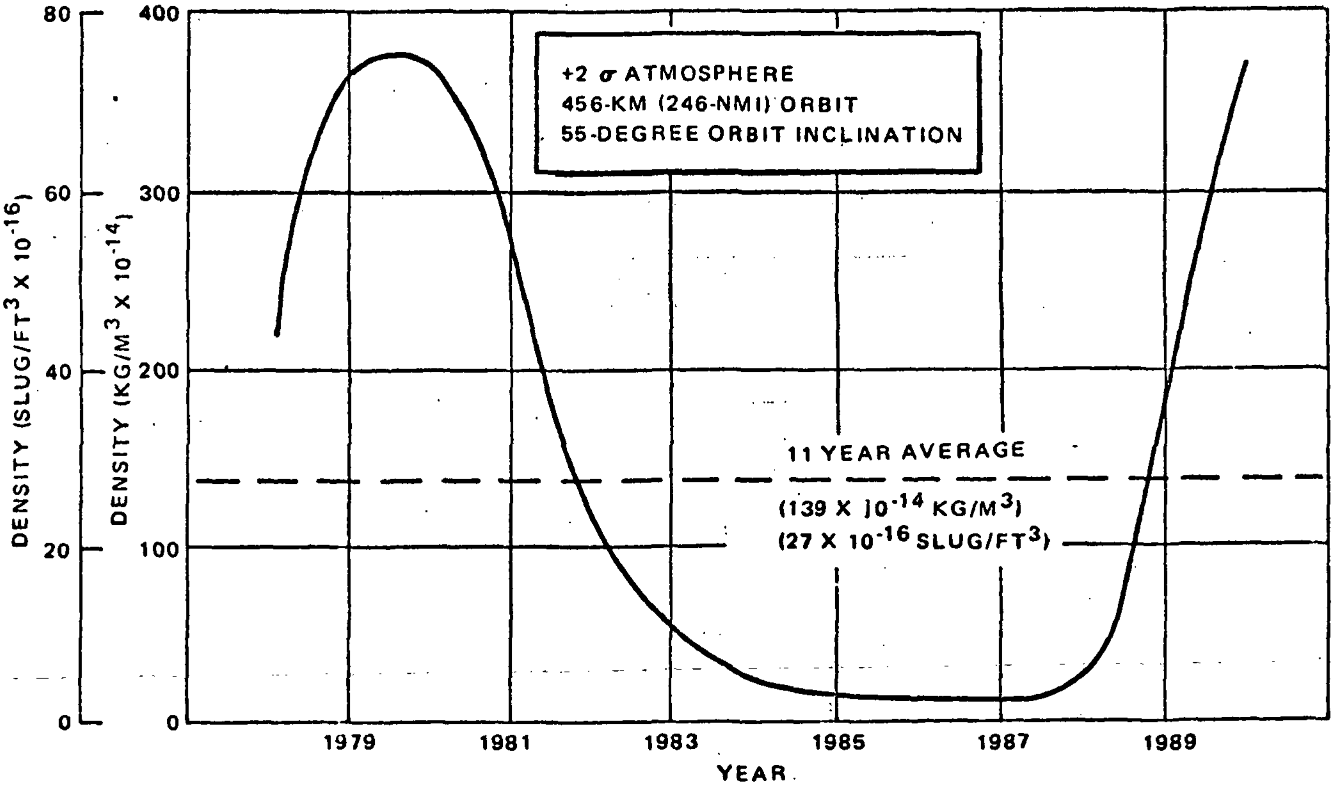
Table 7 (cont'd)

INERTIAL ORIENTATION

Low Thrust Impulse Functions	Orbit Altitude (km) 371	456	556	Comments
Orbit keeping (N-s/90 days)				The orbit-keeping function will require several thruster locations for good efficiencies of aligning the thrusters with the orbital velocity vector.
Maximum	3,340,000	953,000	252,000	
11-yr average	1,510,000	387,000	84,600	
CMG desaturation (N-s/90 days)				
Roll	220,000 (lever arm = 5.04m)			Based on gravity-gradient torques only
Pitch	3,100,000 (lever arm = 42.7m)			
Yaw	3,100,000 (lever arm = 42.7m)			



Orbit-Keeping Impulse as Function of Year



Average Atmospheric Density as Function of Year

Orbit Keeping Impulse
Requirements

Figure 14

The thrusters are sized to required operation of two or more at any given time to permit dumping, yet make efficient use of power. Also nearly-continuous use of adjustments makes for nearly-perfect orbit-keeping and stabilization, by correcting perturbations as they occur.

2.7.1.2 Environmental control - life support (EC/LS) system interface description

The EC/LS system provides oxygen for crew metabolism, maintains total cabin pressure at approximately one atmosphere, removes carbon dioxide and other contaminants from the atmosphere, recovers water from metabolic and waste management processes, manages feces and urine and other human wastes, maintains a thermal balance in the space station cabin, and generally accommodates the life functions of the 12-man crew, including support during extravehicular activity. Three complete and independent systems are provided. Each system is rated at 12-man capacity and each can support the entire crew in the event of loss of the other system. In normal operation, the EC/LS is regenerative, with an essentially closed oxygen loop, and nearly closed water loop. Non-regenerated wastes still occur even in the nearly closed system, primarily because of the added complexity required to achieve complete regeneration. It is these biowastes which offer potential as a resistojet propellant.

In a probable configuration of the EC/LS, CH_4 is produced by the Sabatier process as a waste and would be available as propellant. Alternate operational and mechanization modes may produce waste CO_2 when the Sabatier is off-line, or when adequate water is available

as product from the Sabatier without processing all CO_2 available. Excess water is produced as a result of metabolism of food, and may serve as a propellant. Or the plant may be operated H_2 - rich to insure a desired reaction. Under other approaches H_2 would be available as propellant.

Leakage losses will have substantial impact on availability and type of propellant.

Studies have been conducted to identify, compare and evaluate these sources in the EC/LS and related system. At this time systems are inadequately defined to commit to a rigid effluent specification. As a result, nominal fluids have been identified, and an estimation of contaminants made.

The atmosphere reconditioning subsystem provides cabin air thermal control, humidity control, removes trace contaminants, removes carbon dioxide, and electrolyzes water from metabolic and leakage oxygen. The principal functions and elements of this system are depicted in Figure 5. Preliminary design incorporates the Sabatier converter for reclamation of oxygen, and a surface active carbon dioxide concentrator to increase the concentration of CO_2 for use in the Sabatier reactor. The Sabatier outputs are a) CH_4, b) H_2) and c) traces of H_2, O_2 and N_2.

WATER MANAGEMENT

The Water and Waste Management Subsystems control and conserve the water resources of the space station. See Figure 6. Urine and wash water concentrate is processed in the urine water recoverer.

Water is sterilized and stored for consumption by the crew in drinking or food reconstitution, or as flush for the urine collector. Water is also supplied from this system to the electrolysis cells. Wash water taken from storage is used for crew body wash and hygiene, the dishwasher and clothes washer. After use, it is processed in wash water recovery and sent back to wash water storage. Periodically, the concentrate from the wash water recoverer is directed to the urine water recoverer from processing similar to urine. Reverse osmosis is used to purify wash water. Alternatives of vapor compression to recover water from urine and wash water concentrate, and wick evaporation, are being analyzed. Potable water becomes a potential propellant source. The amount of water available is dependent upon such factors as EVA water use, fecal water loss, urine water recovery efficiency, water in the food supply, leakage, and Sabatier characteristics. This water is expected to méet the standards of Table 4 , and the contractor should design to accommodate water of this purity.

Nominal EC/LS System Fluid Description

For the purposes of developing a nominal resistojet, it is necessary to define a model process stream which the resistojet system must accept. These are defined as Flow Streams. See Figure 12, B/W,R/J System Schematic. Flow Stream 1 corresponds to nominal operation of the Sabatier process. Flow Stream 2 is the expected stream with the Sabatier not in operation. The third is a nominal estimate of the flow from an alternate Sabatier operation. Note the absence of CO_2 due to an excess of H_2. Stream 4 is an estimate of the products available from the water system.

Processing of various combinations of the flow streams may be required.

Flow Stream 1

A mixture of 57% methane (CH_4), 41% carbon dioxide (CO_2), 1% nitrogen (N_2) and 1% water vapor (H_2O) at a total rate of 0.74 lb per hour. Total flow rate shall vary from 0.65 to 0.96 pounds per hour, over a 60 minute period.

Flow Stream 2

A mixture of 98.3% CO_2, 1.2% N_2(nitrogen) and 0.5% O_2 at a total flow rate of 1.16#/hr. Total flow rate shall vary from 1.02#/hr. to 1.51#/hr. over a 60 minute period.

Flow Stream 3

A mixture of 79% CH_4 and 21% H_2 at a total flow rate of 0.43#/hr.

Temperature of Streams 1, 2, and 3 above shall be 70°F at a pressure of one atmosphere (14.7 psia) variable down to 10.0 psia total pressure.

Flow Stream 4

Water would be transferred from EC/LS storage in an intermittent manner at the rate of 1.6#/hr. Storage must be provided for one gallon

2.7.1.3 Logic discussion

The logic system provides the data collection, processing, and commands to operate a resistojet system efficiently. It communicates

with other systems, which must have information about resistojet system status. It converts requirements for orbit maintenance, stabilization, gyro desaturation and biowaste dumping into commands directed to thruster assemblies. Through instrumentation it monitors system status, diagnoses failures and provides summary information including cautions to the crew.

System operation is based on the following rationale:

Propellant shall be managed so that there is neither shortage nor excess over an orbital period.

Individual thruster usage shall be minimized to enhance reliability.

Power requirements shall be minimized.

Operation must take into account the use of various biowastes, mixes, and presence of contaminants.

Information on orbit-keeping requirements are generated in the guidance, navigation and control subsystem. (GNC). Requirements for desaturation impulse are garnered from the control moment gyro (CMG) gimbal angles. The GNC system will also compute impulses required and the thruster firing time. It will accommodate thruster firing inhibit information and determine whether or not there is a requirement for high thrust jet operation, which is not part of the resistojet system. Based on this information, the logic system must command storage tank valve positions and determine availability of each propellant or combination. Quantity of stored biowaste material must be measured before and after operation of the system.

System logic compares the impulse requirement and propellant quantity available and makes a classification of propulsion system and technique to be used. If a very low requirement, propellant is used without heating. For even lower requirements, a determination to dump a portion is made. At the other propulsion requirement extreme, mixed propellants, or water must be handled. The system computes number of jets to be used, consistent with the rational above.

Sensors will provide the required physical inputs and provide for on-board and ground monitoring at the appropriate level of complexity, but adequate for trend analysis. Basic information could be an on-off electrical signal, mechanical position of a valve, solenoid analog signals from a thermister, or the position of a pressure-sensing diaphram. Provisions must be made to condition signals for appropriate processing. Fault detection isolation and switching and notification of crew shall be automatic and included in system logic. Malfunctions of the mechanical equipment is judged non-critical and is part of normal operational status. These items are classified as fault detection. Failure of certain of the instrumentation is considered critical, and would result in a caution notification of the crew.

2.7.1.4 Prototype requirements

The purpose of the design, development and demonstration test of the system breadboard model is to explore the operational problems and technology status of a propellant management and control system under simulated, representative application, duty cycles. Such a

program will provide a versatile tool to explore the influence on thruster technology requirement trade-offs of propellant management and control options. It is also useful to illustrate, by status survey and test, the adequacy of existing component technology to meet application requirements of typical high impulse biowaste resistojet applications. By exercising the system in a variety of duty cycles and modes, the logic and software interface of the system to a mission will be explored. In addition, the program will provide planning and design data to future manned space station studies and over-all system demonstrations. Specific items, such as gas pumps, will be identified as requiring further life or performance enhancement. In areas not requiring additional new effort, additional confidence will be achieved through use in new environments or duty cycles. Complexity levels shall be adequate representatively load the system, to exercise the system and to demonstrate the logic capacity to handle complex requirements. It shall not be of such a complex design so as to provide full man-rated redundancy, but shall incorporate cross-over and failure isolation capability for use in duty cycle simulation. The system shall be so constructed as to accept simulated commands and signals of the CMG and GNC systems and process the information into coherent control commands The system shall be capable of accepting signals which simulate actual system physical parameters such as temperature, pressure, valve position, etc.

The system should demonstrate the potential to efficiently manage the problem of minimization of power requirements and mass conservation or dissipation as necessary, and in general, to follow the rational under "Operation", above. Within practical

constraints of the program, the logic shall closely follow that for the actual system. Similarly, caution and warning systems and measurement systems and instrumentation systems shall be configured the same. A problem simulator shall be provided to simulate inputs of GNC and CMG systems to provide problems related to system status such as nozzle unavailable.

2.7.2 Development plan

In addition to the above mentioned requirements definition study, supporting recommendations for the implementation and development plan were provided. This work was conducted in close cooperation with the contract technical representative and included recommendation of specific items as probable development sequence milestones, design review objectives and hardware quantity. In general, these preliminary recommendations were reviewed, modified, and incorporated as deemed appropriate by the Government for use in their procurement planning. The material is incorporated in substance in the sixth and seventh monthly progress reports.